Nuclear Power

THE JOURNAL OF BRITISH NUCLEAR ENGINEERING

A·E·I–
John Thompson
Nuclear Energy
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Limited

Balfour Beatty
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Nuclear power for the nation's future

AN EXAMPLE of industry pooling its resources to prepare for a mighty project is the linking of the A.E.I.—John Thompson Nuclear Energy Company with two important firms of Civil Engineering Contractors—Balfour Beatty and Co. Ltd., and John Laing and Son Ltd.

To the strength of the A.E.I.—John Thompson Nuclear Energy Company and its constituents (British Thomson-Houston, Metropolitan-Vickers and John Thompson) is added a fund of knowledge in the civil engineering field.

The Balfour Beatty Group has a world-wide reputation in all forms of engineering and construction work and is at present carrying out major contracts for the Central Electricity Authority.

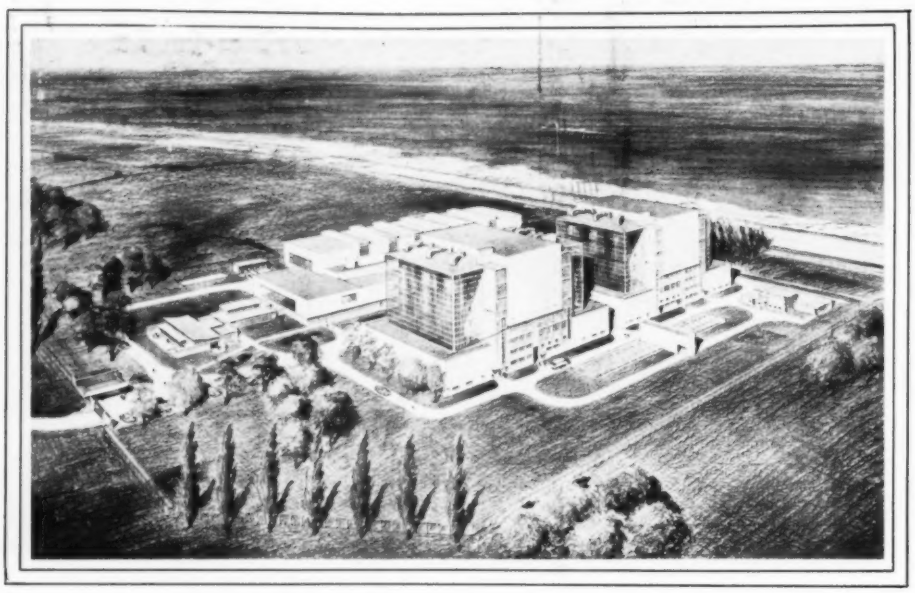
John Laing and Son Ltd. has carried out building and civil engineering work at the first Government Atomic Energy Establishment at Windscale and is at present engaged in the construction of power stations in the United Kingdom, as well as in major development schemes in Canada.

RADBROKE HALL · KNUTSFORD · CHESHIRE

July 1957 Volume 2 Number 15 3s 6d

NUCLEAR POWER

Harwell
Windscale
Capenhurst
Calder Hall
Chapelcross
Dounreay
Bradwell



Architects drawing of nuclear power station now under construction at Bradwell, Essex by N.P.P.C. for the C.E.A.

Experience in the nuclear field by member companies of The Nuclear Power Plant Company Ltd., is apparent by the plant which has been made and is in successful operation in the various Atomic Energy Establishments in Great Britain.
Now in united strength as N.P.P.C., these companies have been awarded the contract to construct a nuclear power station for The Central Electricity Authority at Bradwell in Essex.

NPPC

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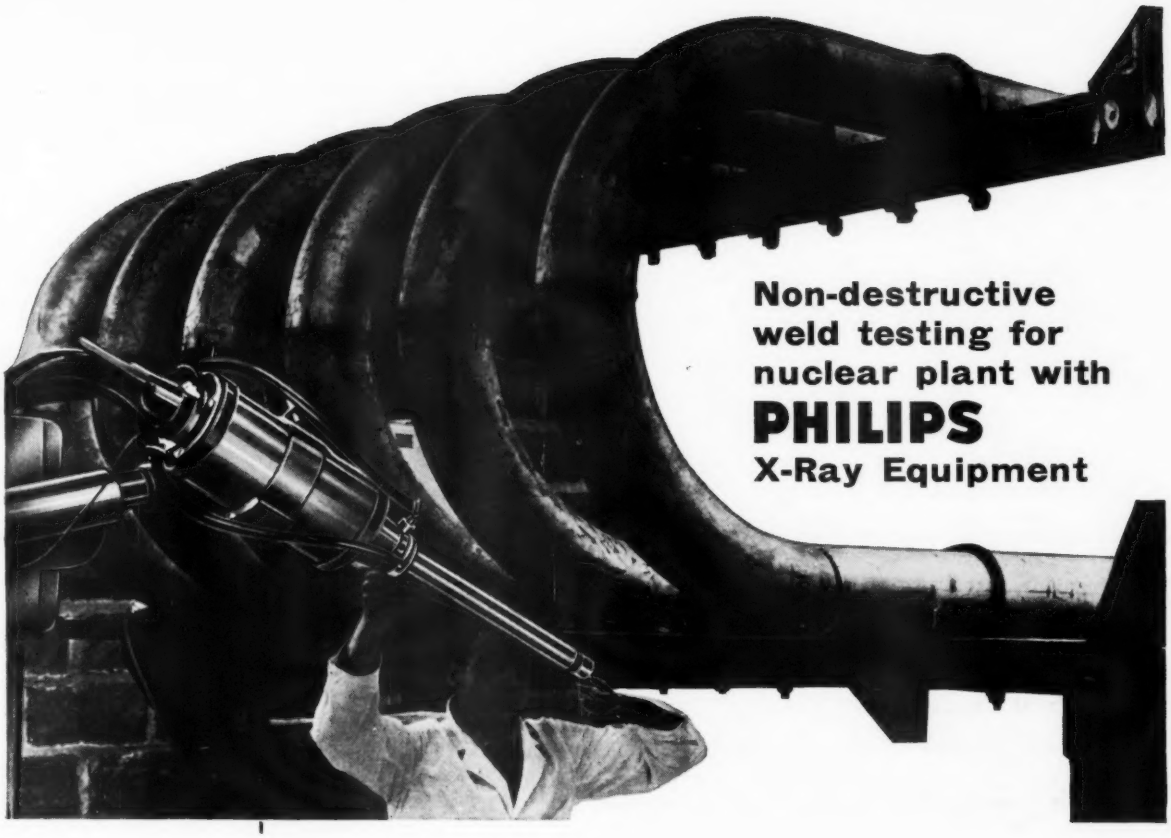

Non-destructive weld testing for nuclear plant with PHILIPS X-Ray Equipment

Philips portable Macrotank 'D' X-Ray Units are now in use on the inspection of site welding at Dounreay

Welded joints in this stainless steel pipework for liquid metal heat exchangers are here being inspected to extremely high standards with Philips X-Ray equipment. The heat exchangers, together with all liquid metal circuits, and principal vessels, are under construction by John Thompson Limited, Wolverhampton, for the U.K. Atomic Energy Authority's first full-scale breeder station at Dounreay, Caithness.

Philips manufacture a wide range of X-Ray equipment suitable for non-destructive weld testing on nuclear reactor installations.

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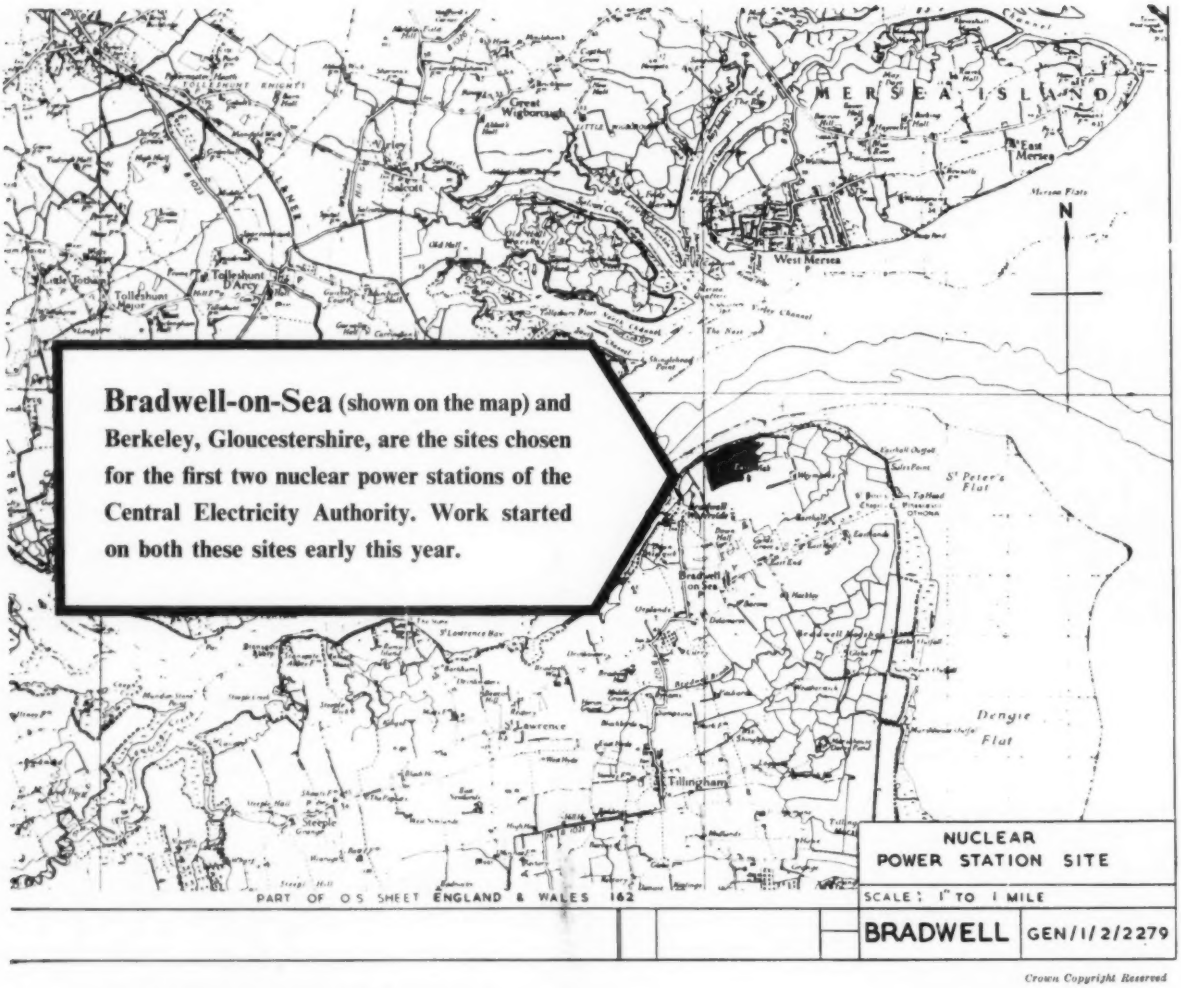
Electricity from Nuclear Energy



Bradwell-on-Sea (shown on the map) and Berkeley, Gloucestershire, are the sites chosen for the first two nuclear power stations of the Central Electricity Authority. Work started on both these sites early this year.

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The growing need for power

As Britain's industrial efficiency increases, so does the need for power. The demand for power doubles every ten years; supplies of home-produced coal do not keep pace with these developments. Nuclear energy will do much to make up the discrepancy between the demands for electric power and the available coal supplies.

Central Electricity Authority has placed contracts for two nuclear power stations, sited at Bradwell in Essex, and Berkeley in Gloucestershire. Negotiations are proceeding for a third station which, subject to consent, will be erected at Hinkley Point near Bridgwater in Somerset. These three stations will have an aggregate capacity of some 850,000 kilowatts.

The Government's revised nuclear power station programme provides for 19 nuclear power stations to be completed by 1965. They will develop from 5,000 to 6,000 megawatts of capacity and add to the national power resources the equivalent of some 18 million tons of coal a year.

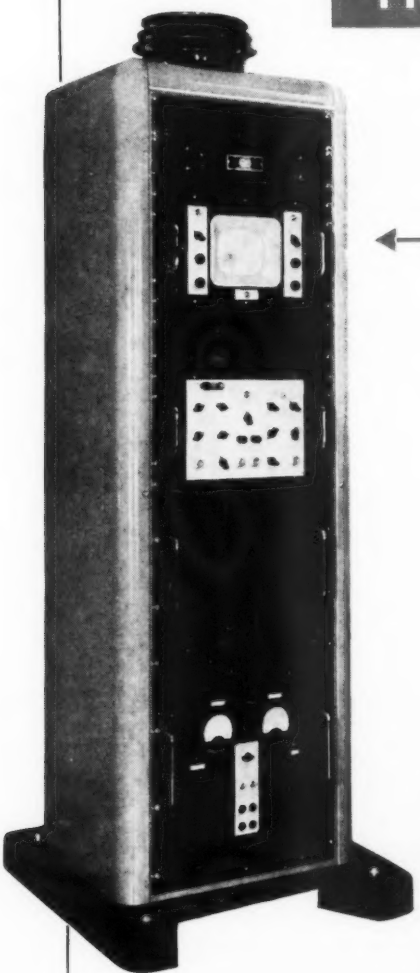
As the demand for power grows, nuclear energy will become more and more important as a source of electric power, upon which the economic future of the country so largely depends.

CEA

SUNVIC

NUCLEAR

INSTRUMENTATION



Pulse Height Analyser type PHA.2 for sorting a complex pulse amplitude spectrum into groups of known height. A random sample of up to 1250 p.p.s. can be analysed into 100 channels, each capable of counting more than 16,000 pulses.

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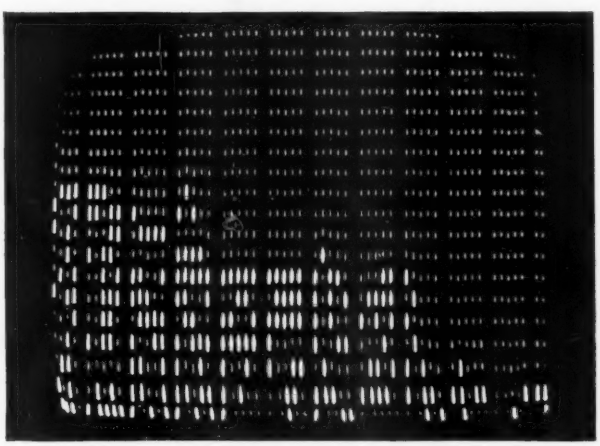
A typical display pattern for PHA.2 is illustrated below. Dimensions and technical specifications are contained in Data Sheet No. 13, which is available on request.



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Shaping the Future

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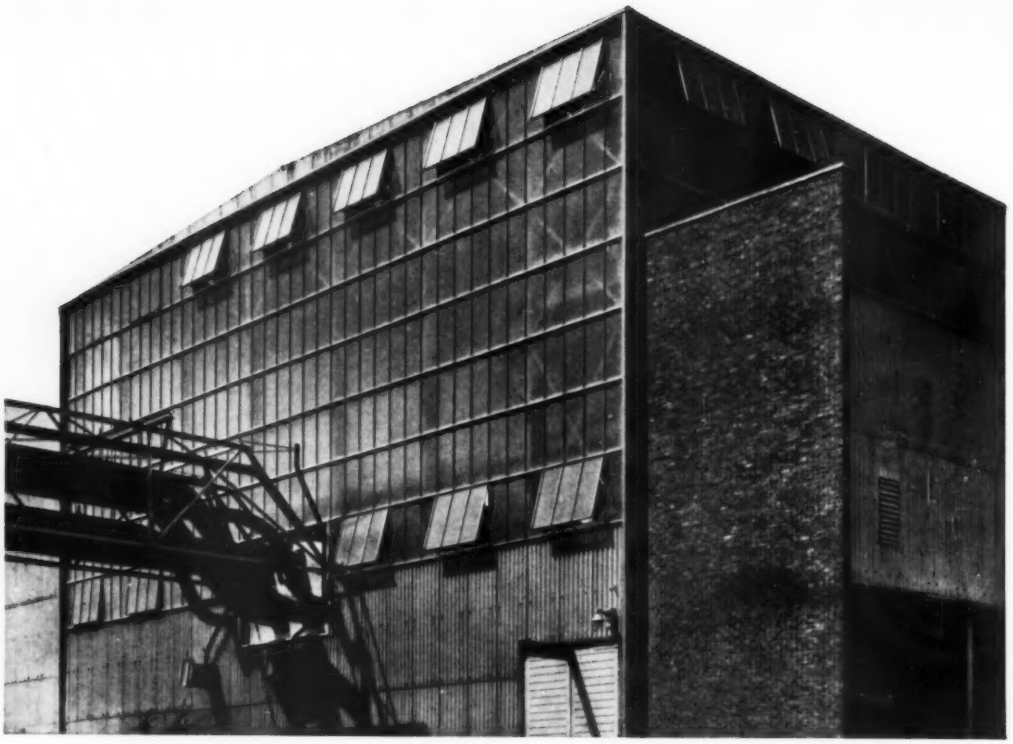
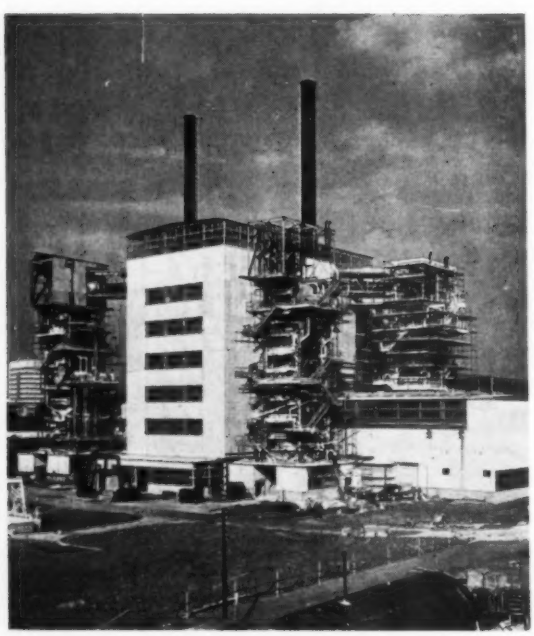


Photograph reproduced by courtesy of the United Kingdom Atomic Energy Authority.

HILLS (WEST BROMWICH) LIMITED
at Britain's Atomic Plants



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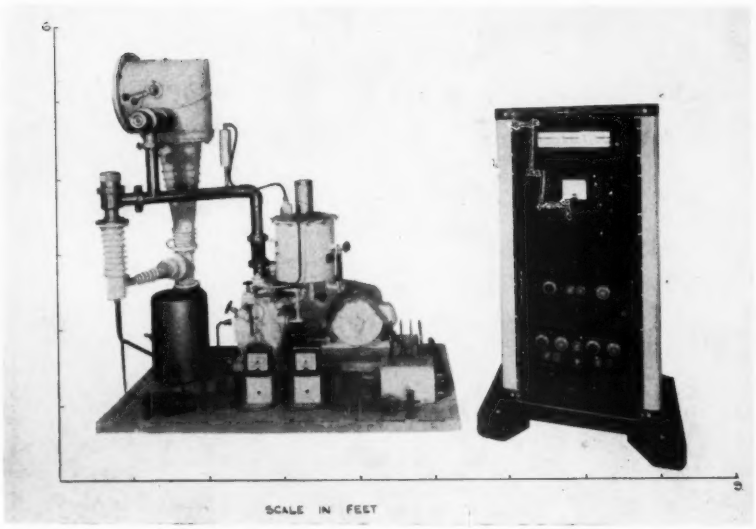
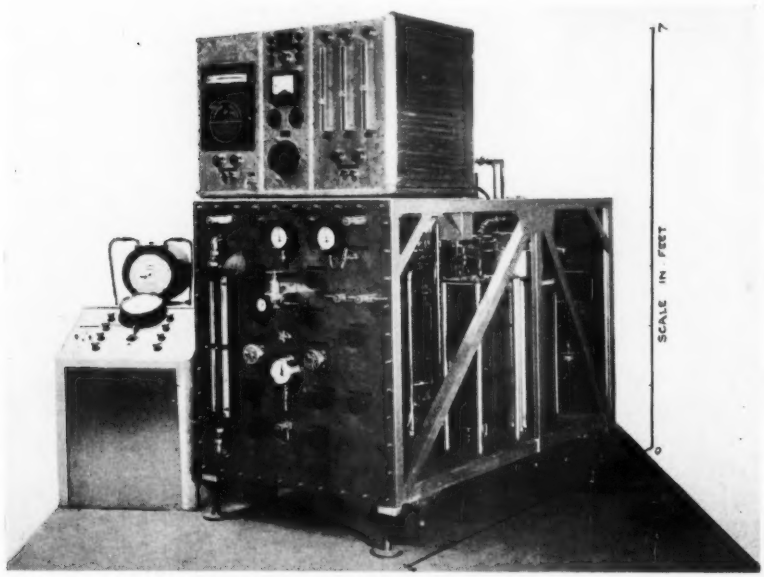


GAS BALLAST PUMP AND CONTROL UNIT
unit includes furnace control



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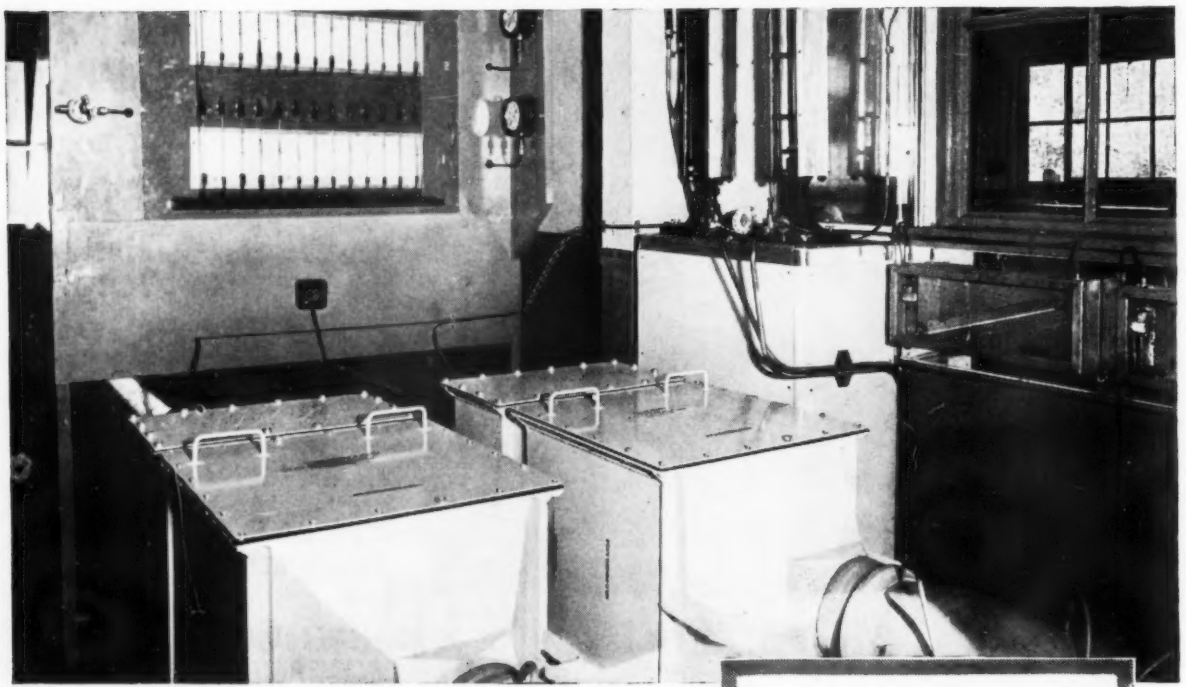

A new range of Vokes filters has been developed to ensure efficient filtration where radioactive dust (such as in nuclear energy installations) or dustborne bacteria could be really dangerous. In these cases, even submicron particles of dust can have serious results, and it is to arrest these minute particles that Vokes now offer their 'Absolute' Filters.

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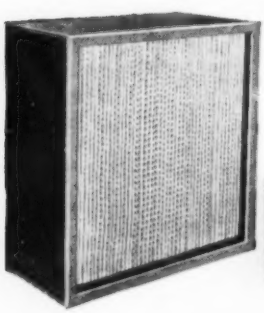

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How Vokes Filters are individually tested

The test—known as the 'methylene blue penetration' test—consists of a comparison of dye stains between the inlet and outlet sides of the filter. A 1% solution of methylene blue dye in water is passed through an atomiser. In evaporating, the water droplets leave dye particles of a known size in the air-stream. By number, 90% of these particles are below 0.5 micron in size, while 50% of them measure less than 0.05 micron. These are the dangerous particles stopped by the Vokes 'Absolute' Air Filters—to your plant's benefit. The box-type canister shown in the photograph was tested at 200 c.f.m. and with a water gauge drop of no more than 1.25 in. the dye penetration was only 0.003%, giving a test efficiency of 99.997%.

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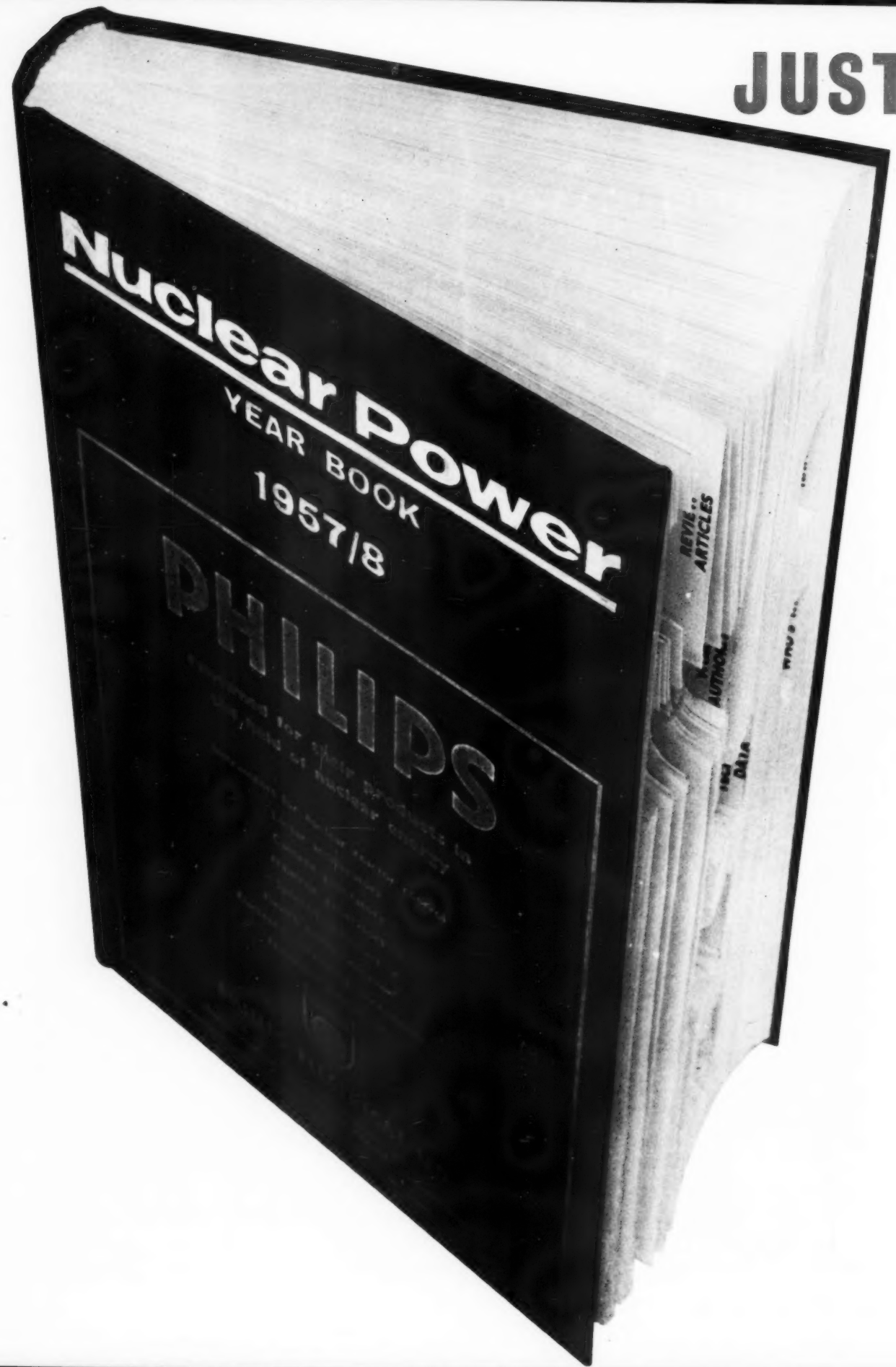

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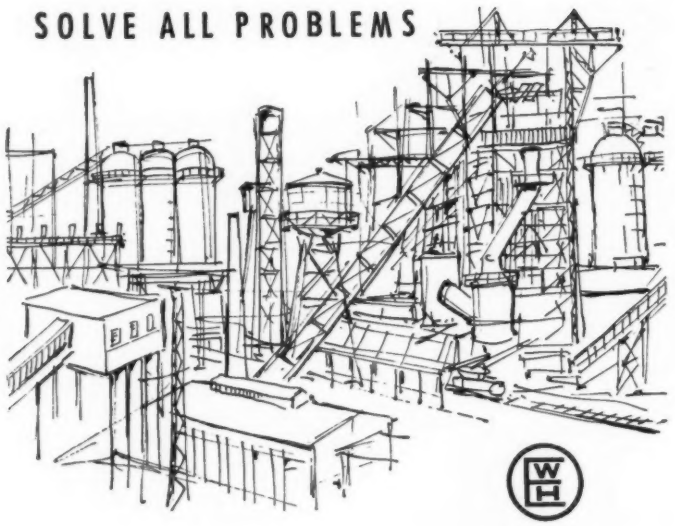

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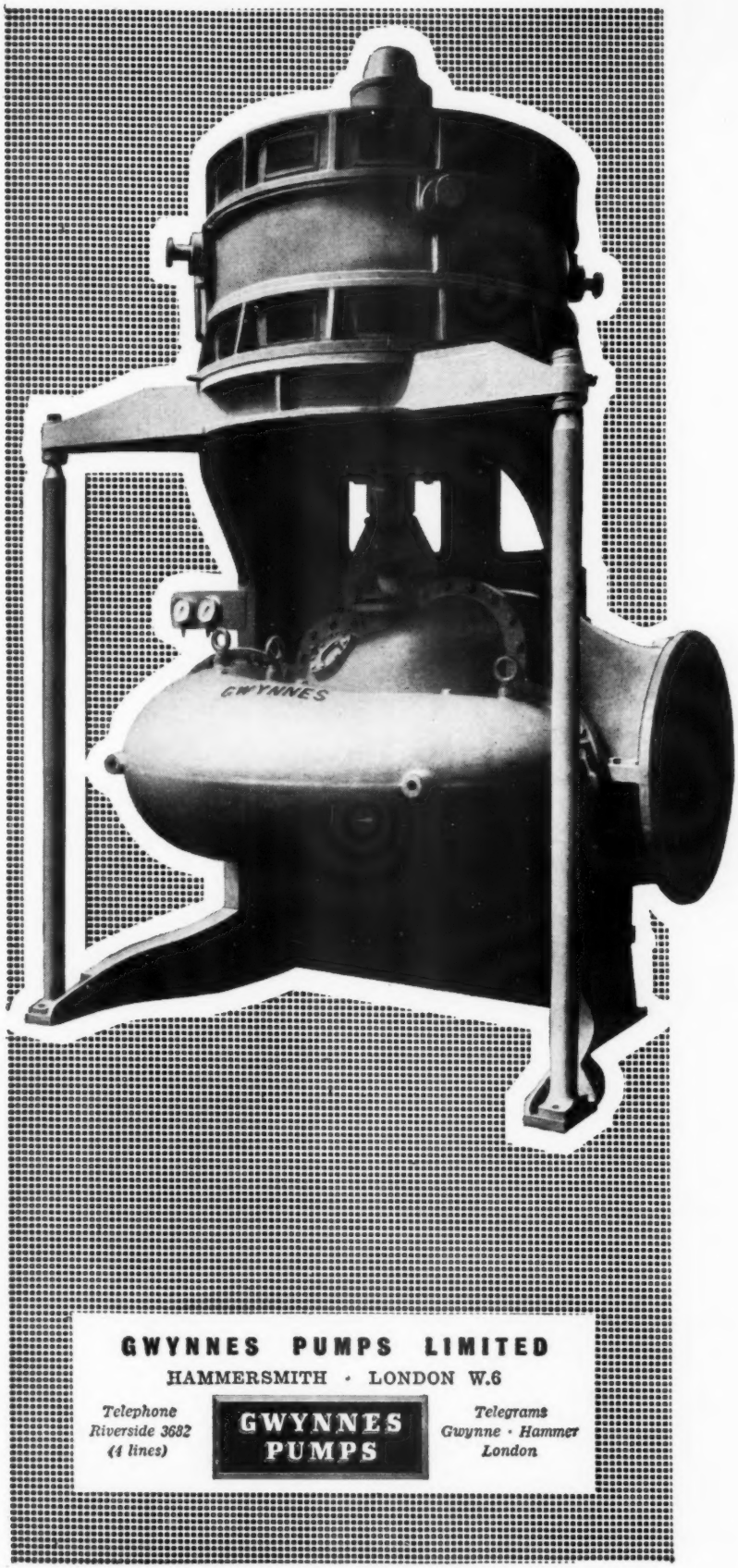

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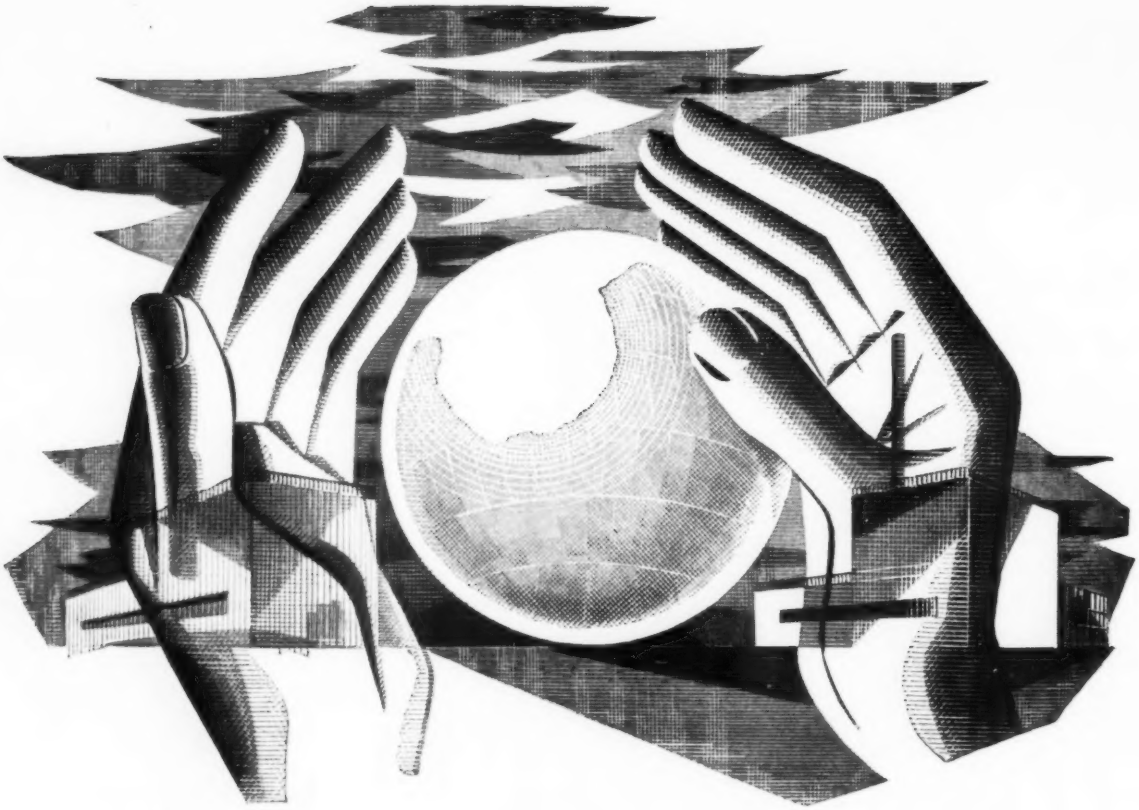

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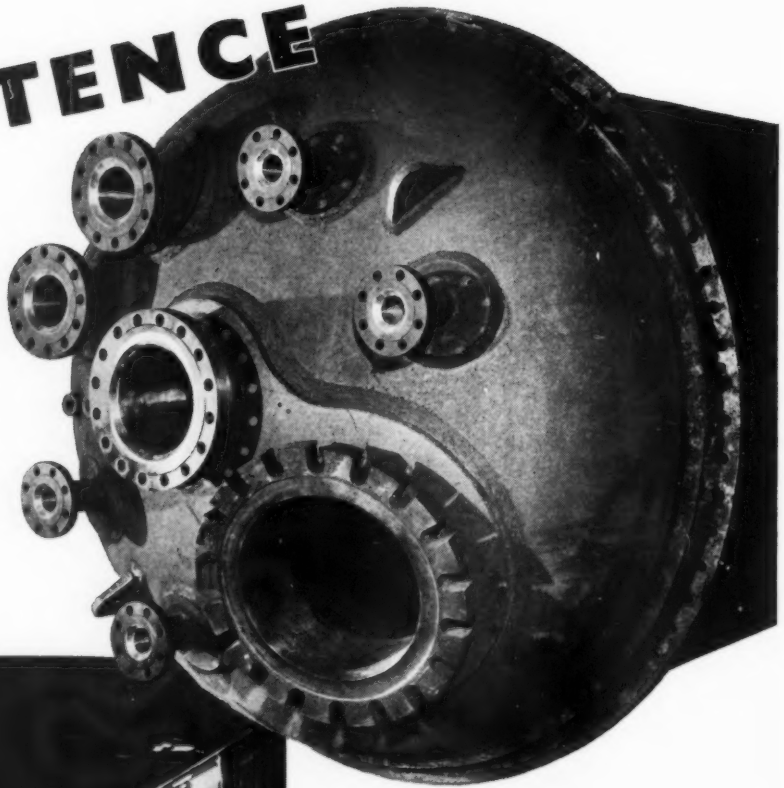

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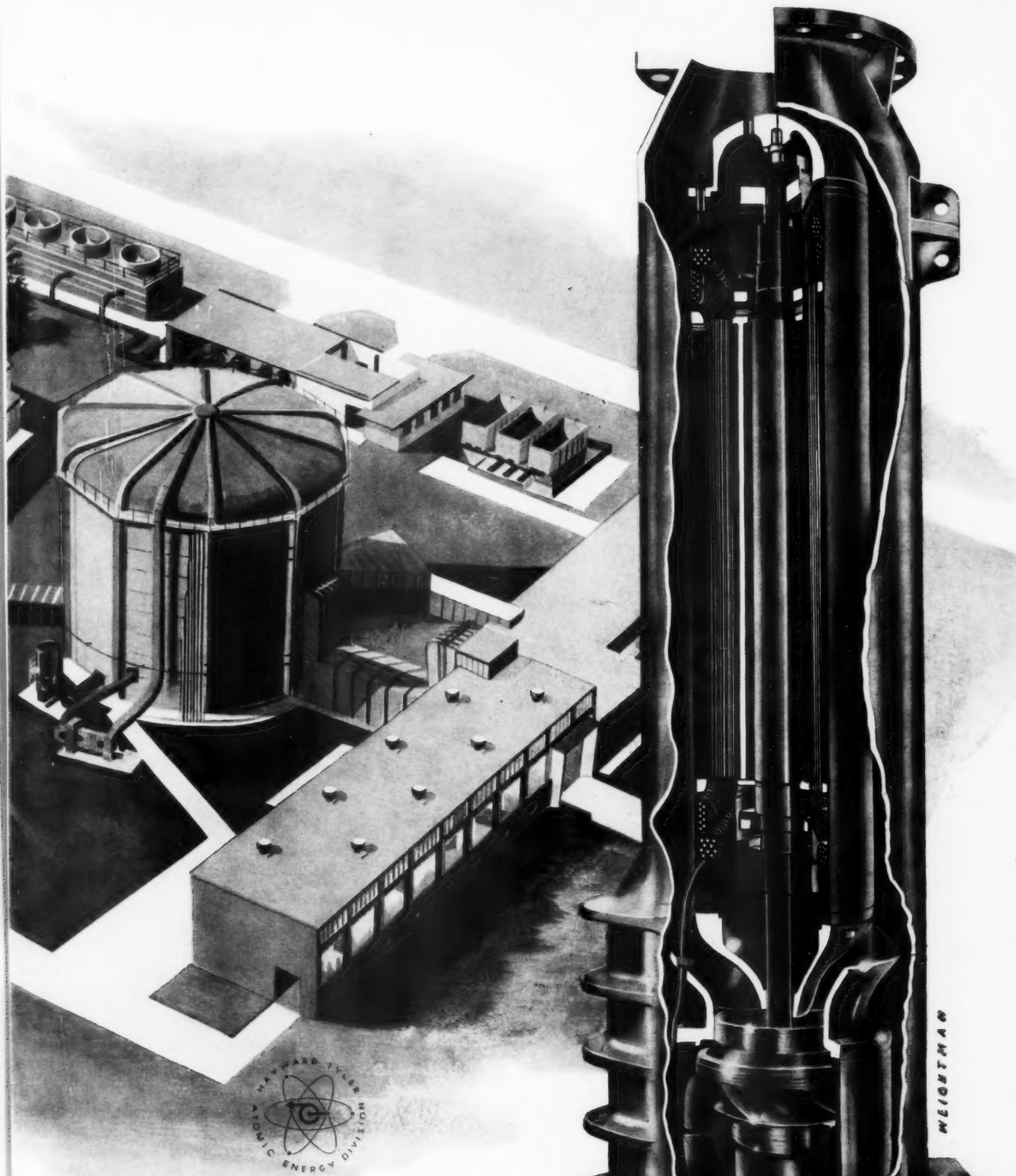

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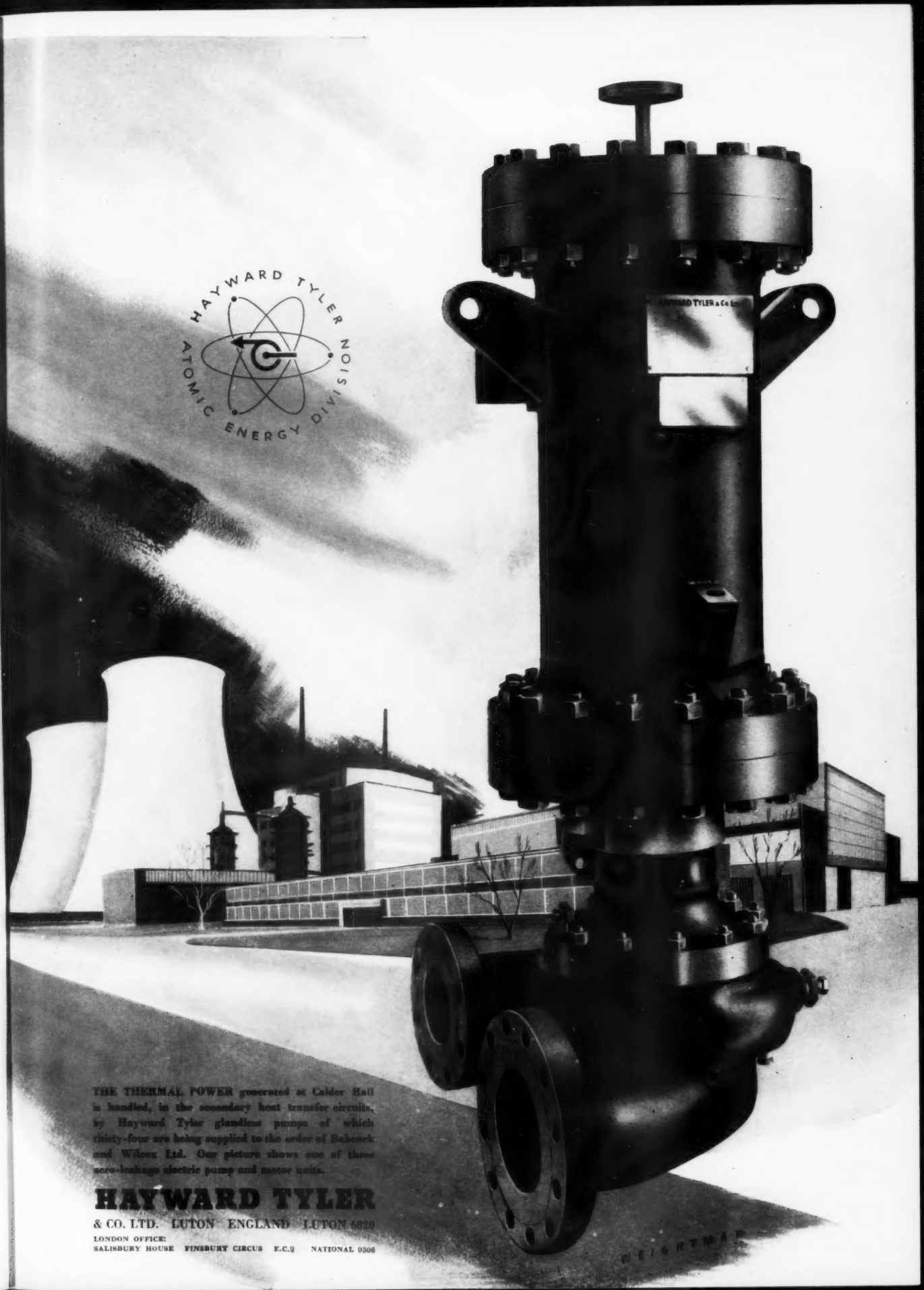

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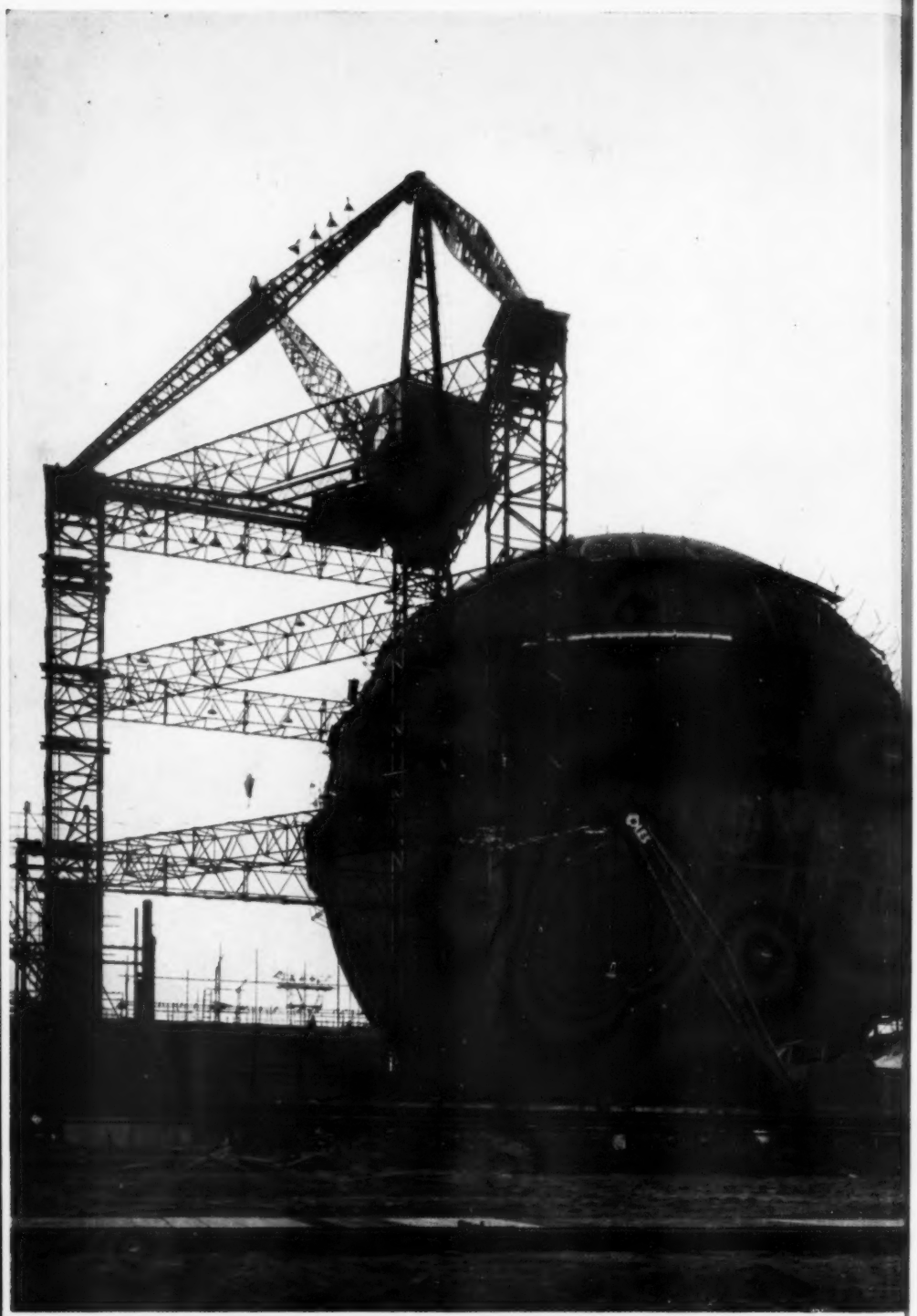
Shaping the pattern of the nuclear future

Two nuclear power projects of global significance have been undertaken by the G.E.C.—Simon-Carves Atomic Energy Group. In Scotland, the Group is to construct a 320 MW nuclear power station for The South of Scotland Electricity Board. At Dounreay, The Motherwell Bridge and Engineering Company Ltd. (a member of the Group) is building the 135 ft. diameter reactor-containing sphere for the U.K. Atomic Energy Authority's fast breeder reactor. The G.E.C. is installing the electrical generating plant.



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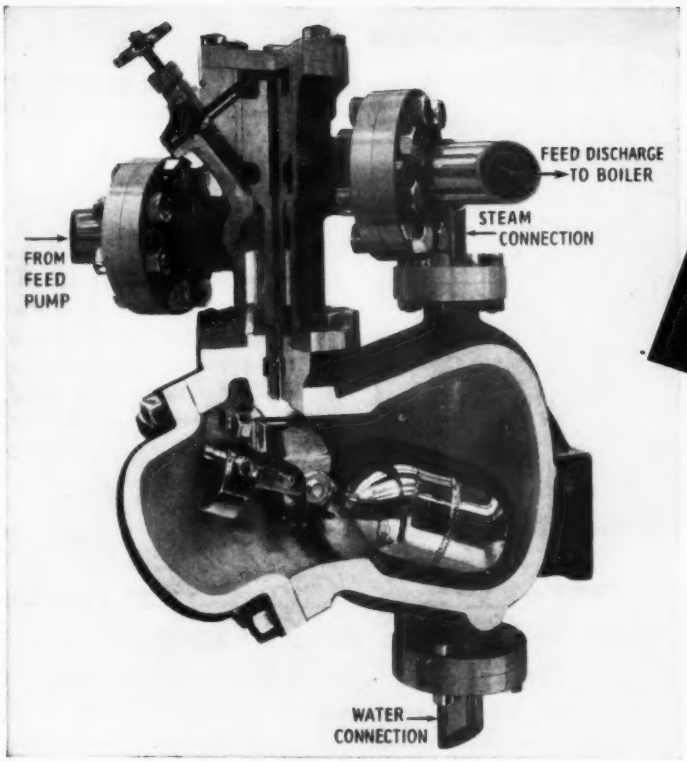

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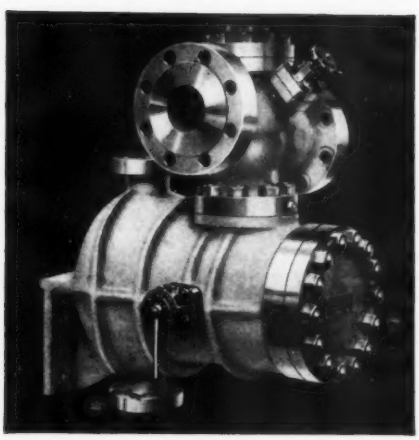

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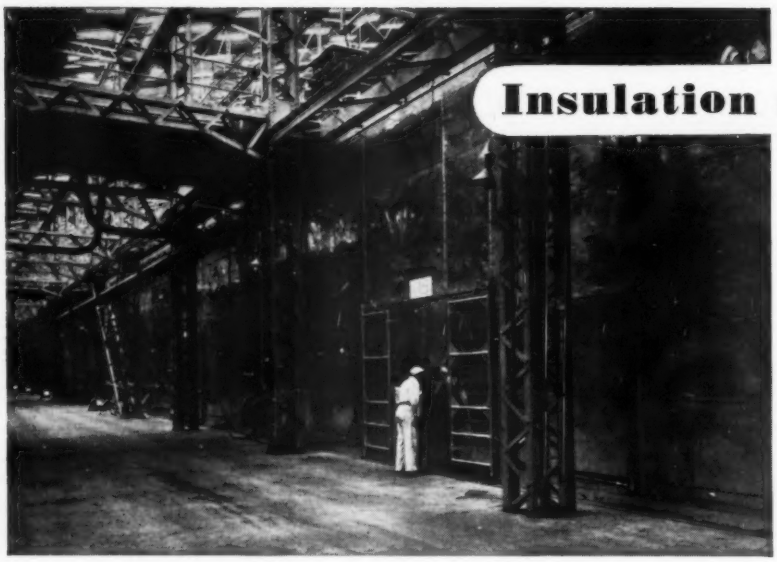

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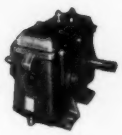

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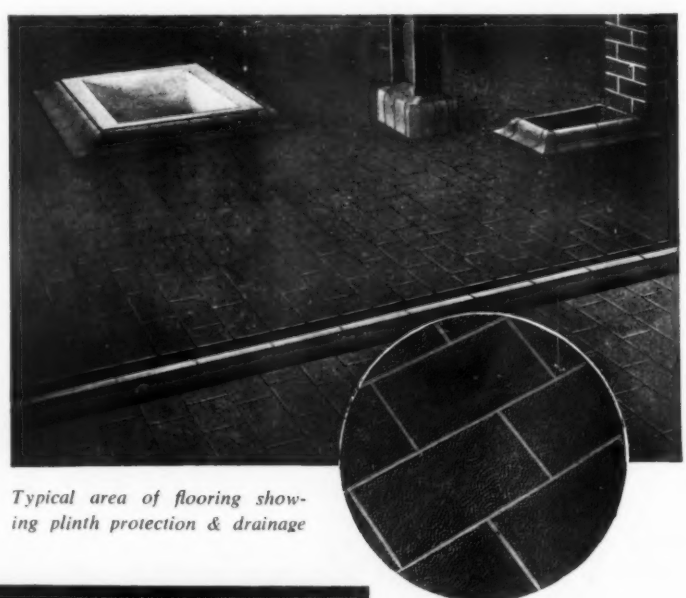

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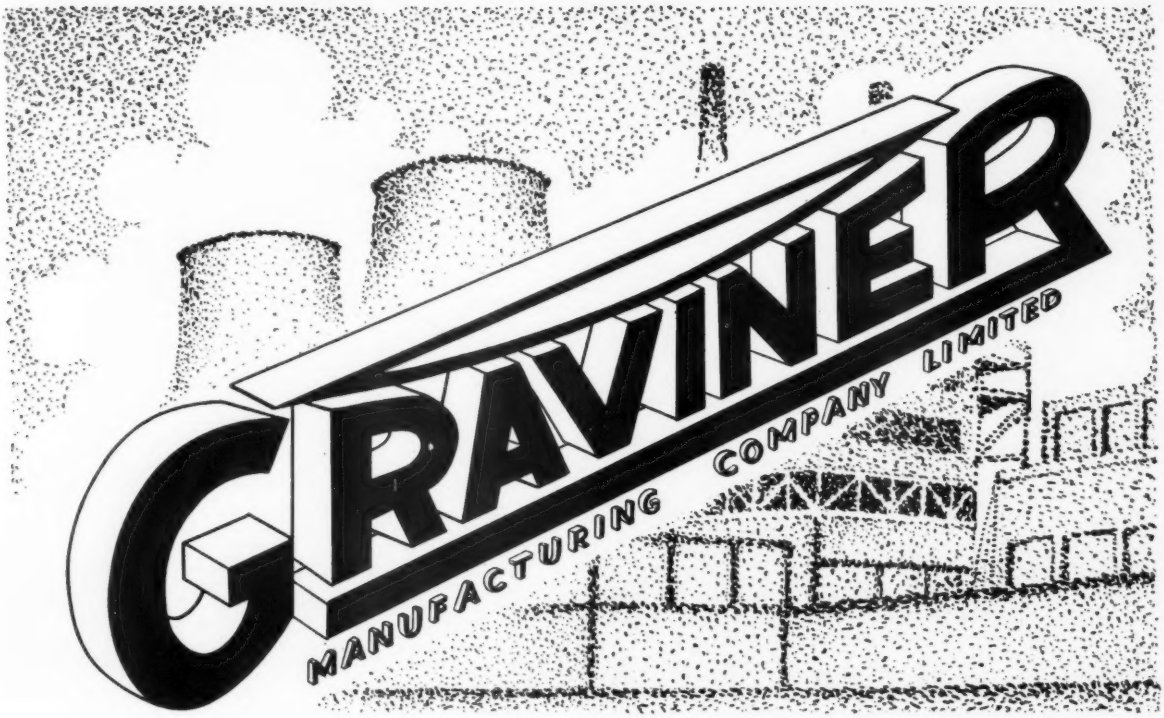

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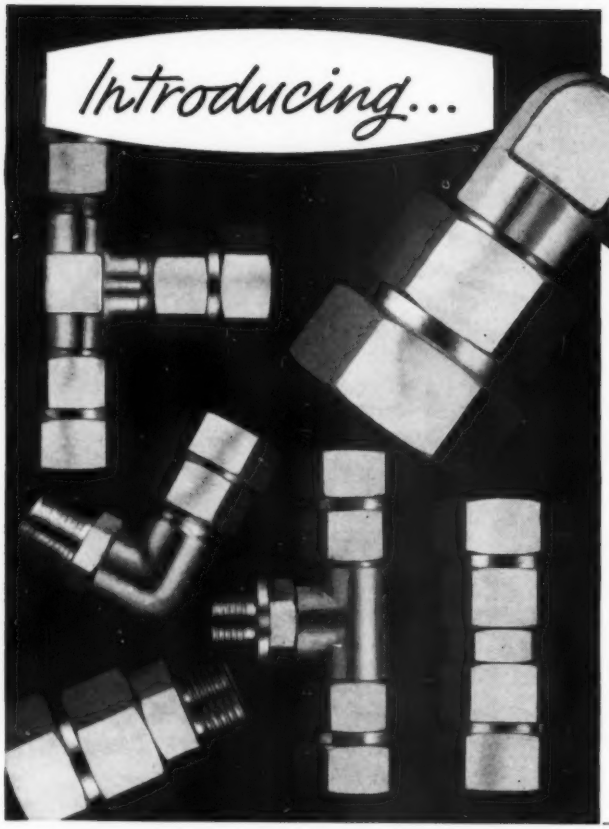

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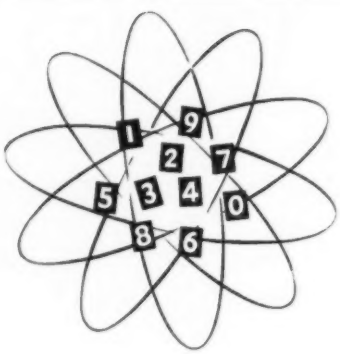

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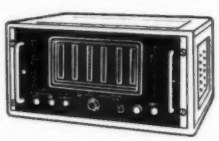

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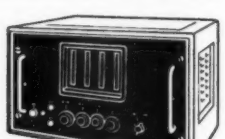

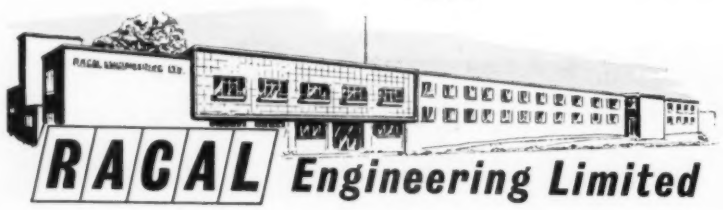

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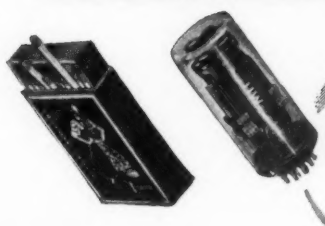

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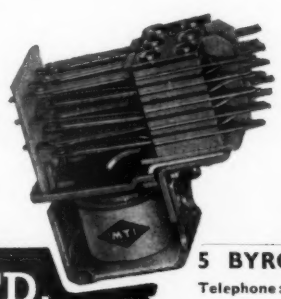

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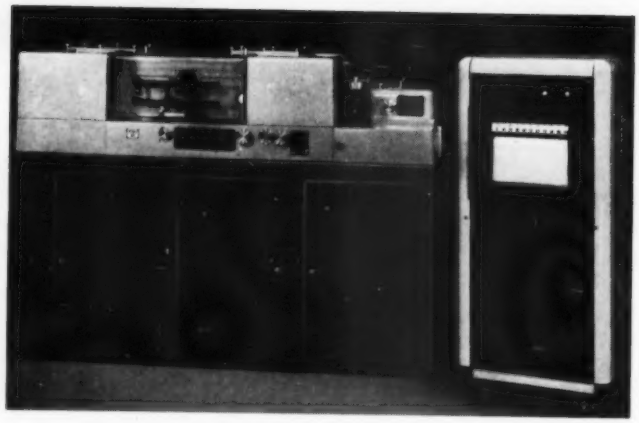

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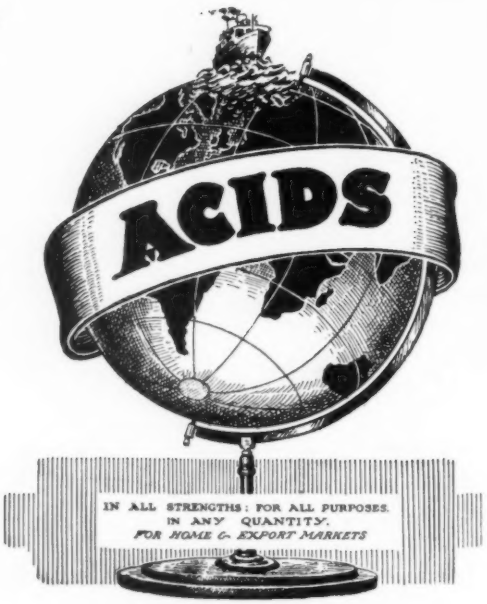

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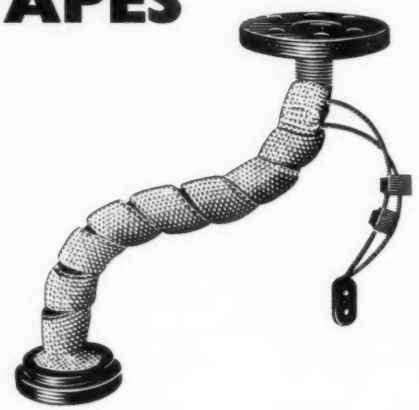

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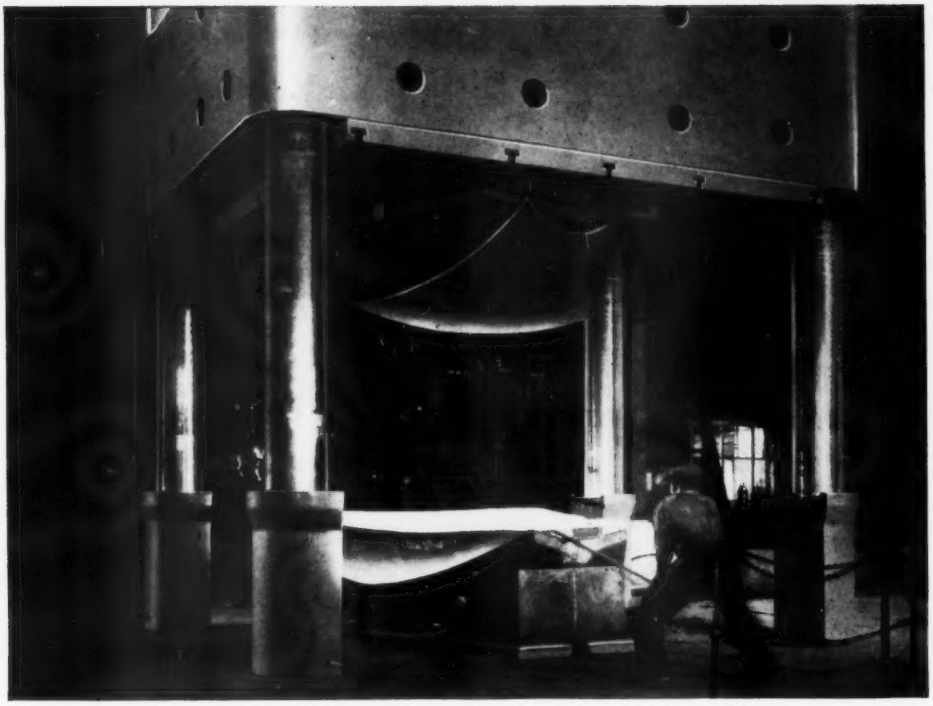

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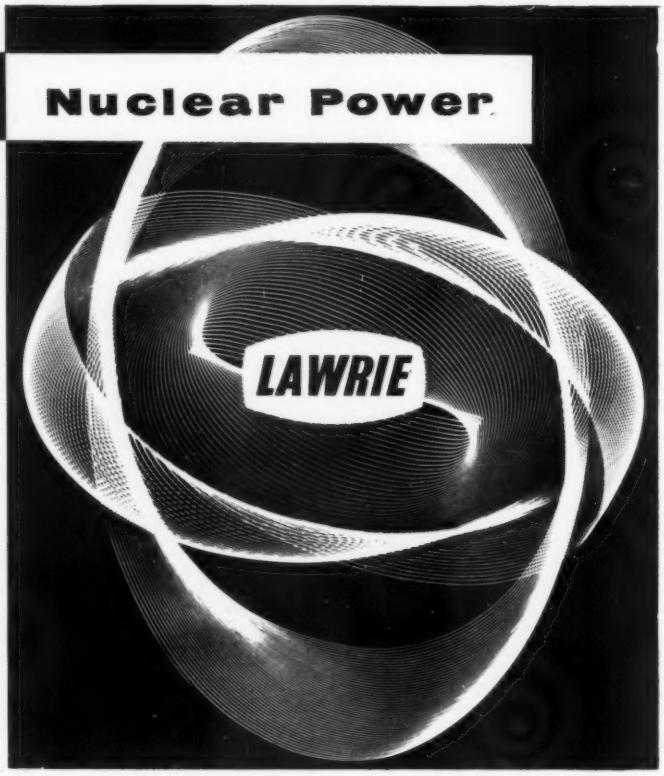

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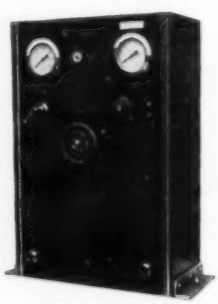

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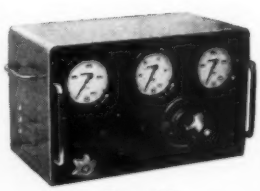

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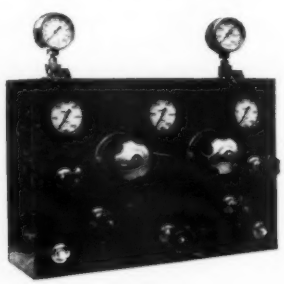

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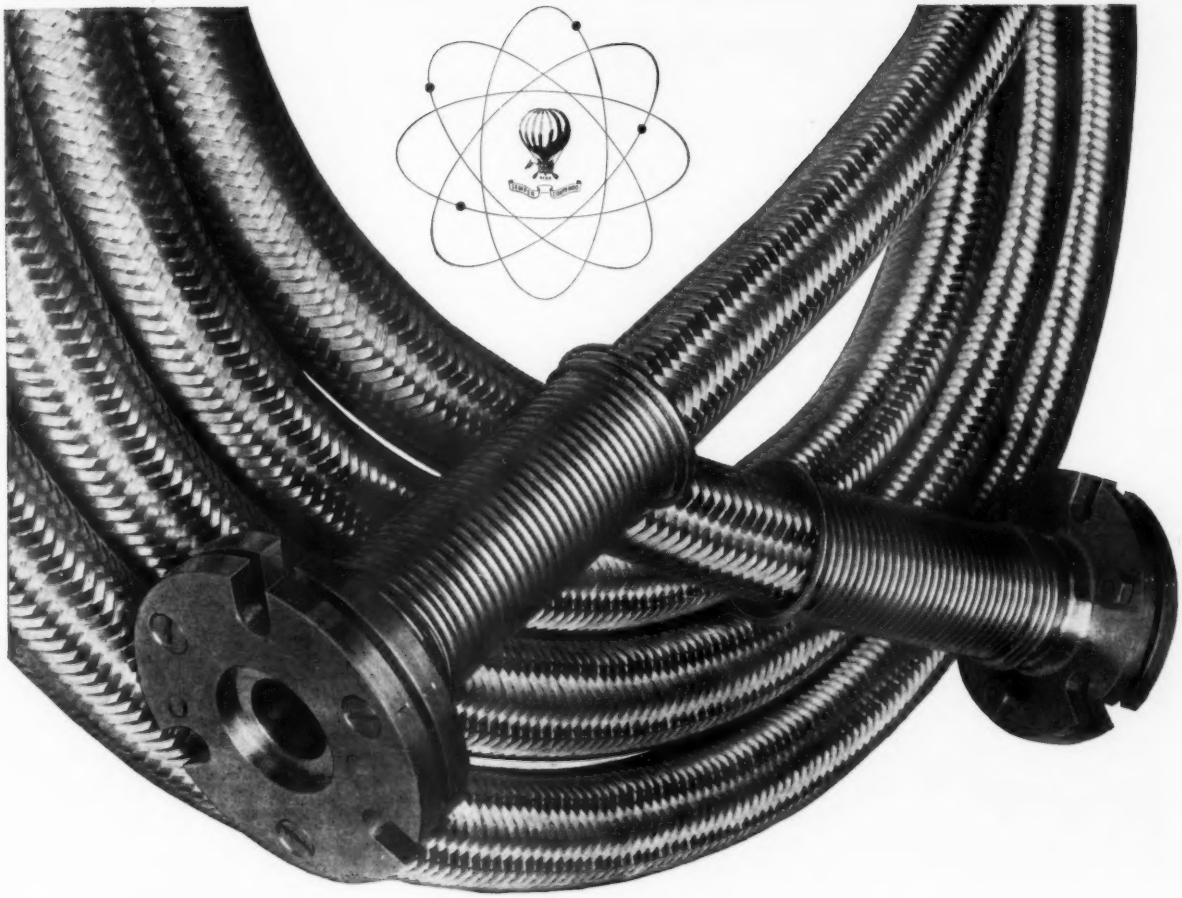

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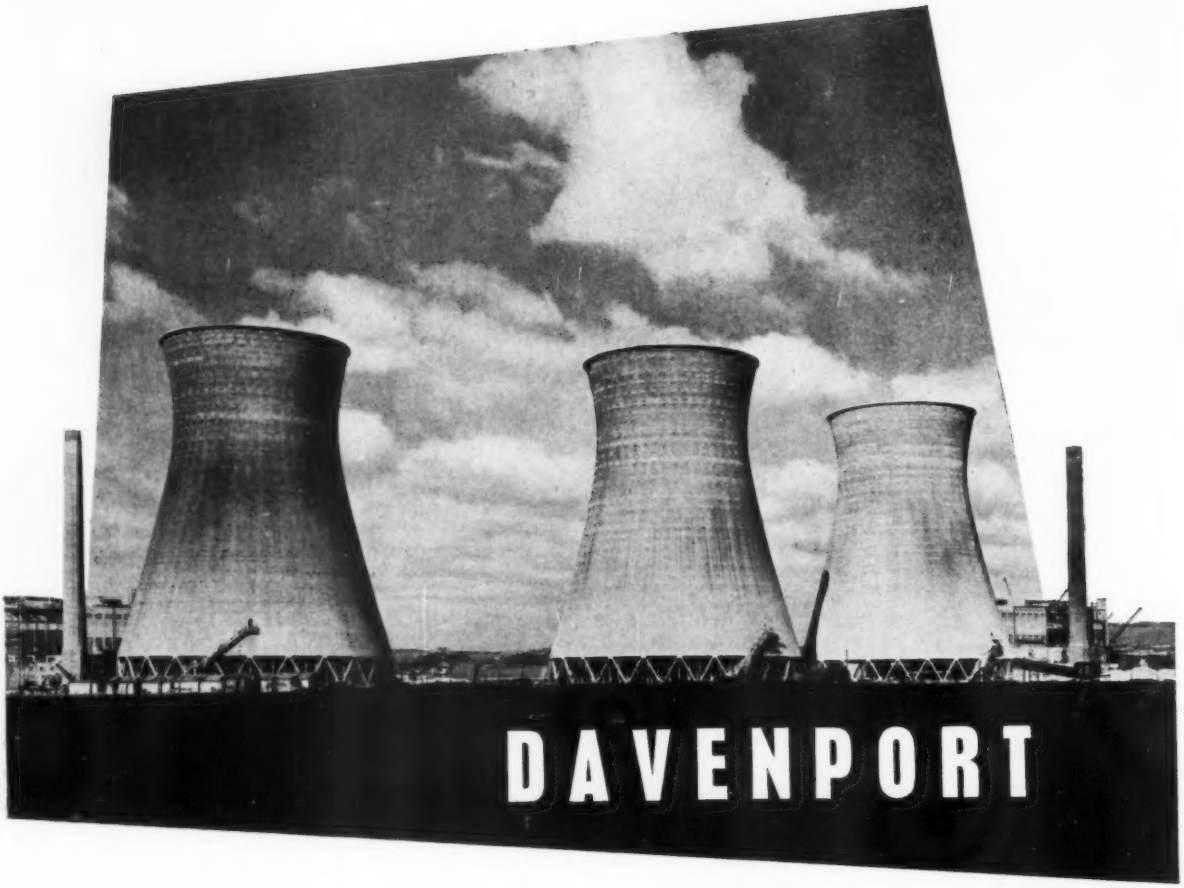

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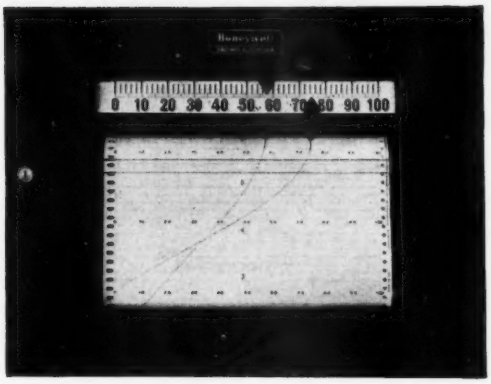

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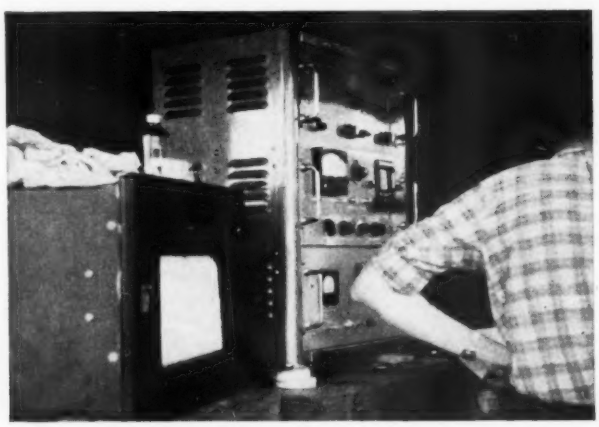

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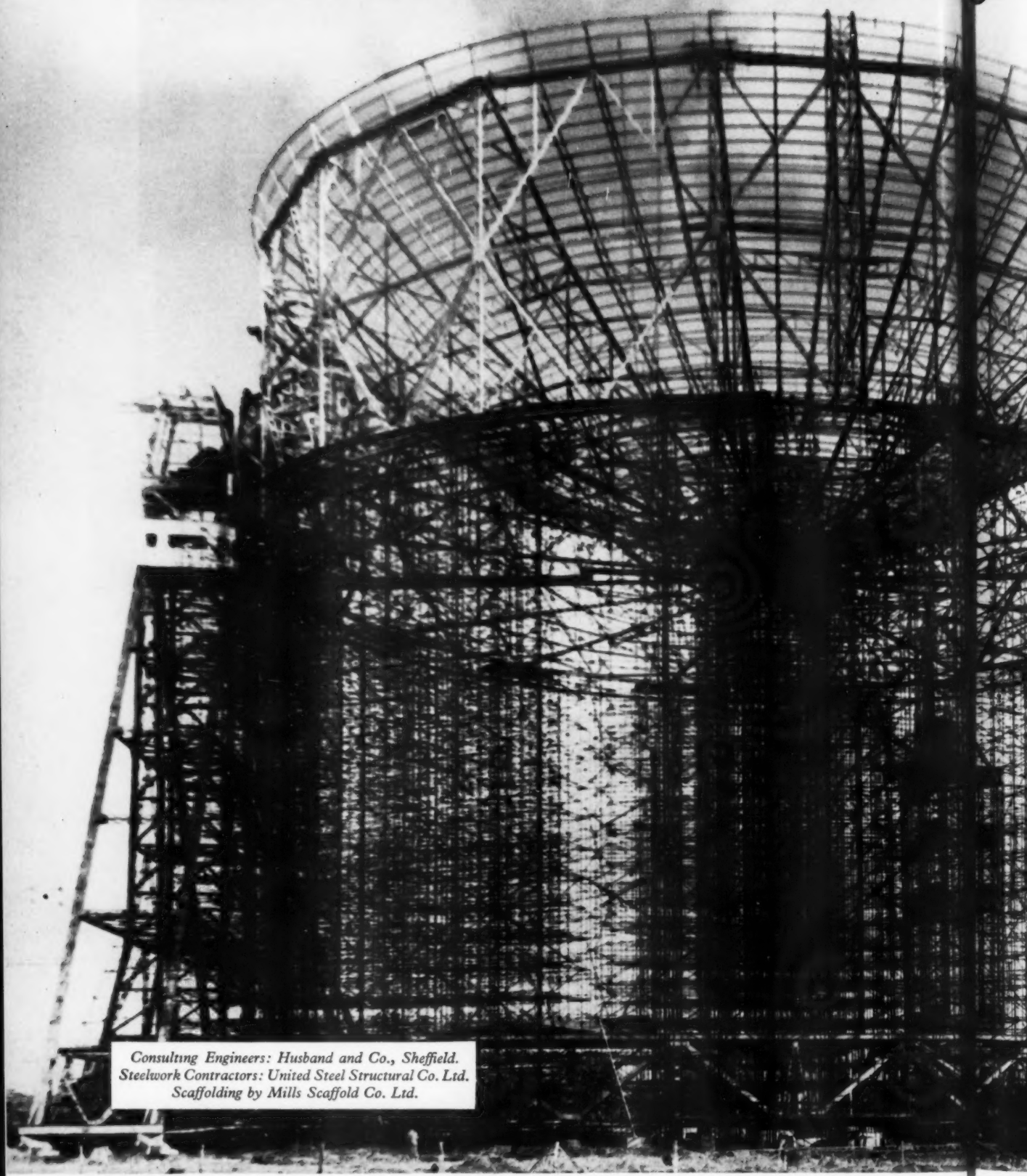

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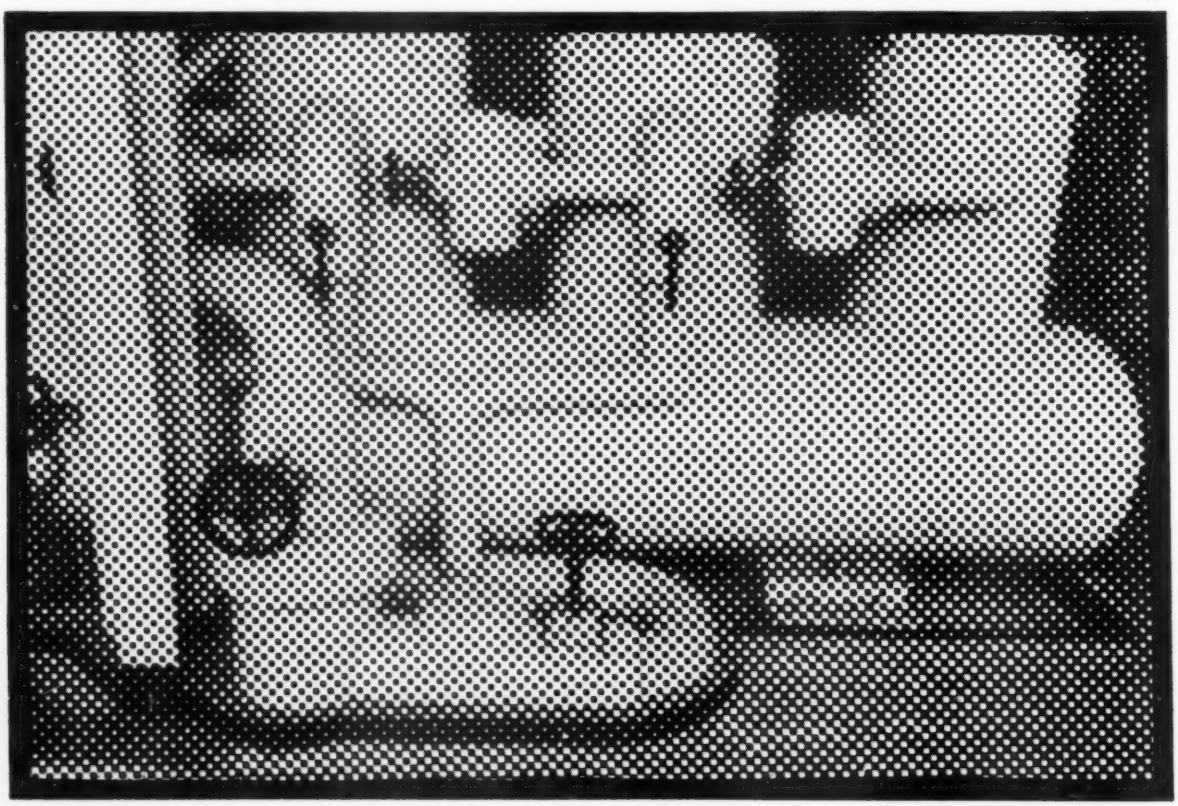

JULY 1957 VOLUME 2 NUMBER 15

This month Nuclear Power focuses attention on pumps...
...pumps for nuclear reactors

Due for completion early 1958, the new UKAEA London headquarters are at the corner of Lower Regent Street and Charles II Street. Main Contractors are Trollope and Colls; joint architects are Trehearne & Norman, Preston & Partners and Leslie C. Norton

Nuclear Power
The journal of British nuclear engineering

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at

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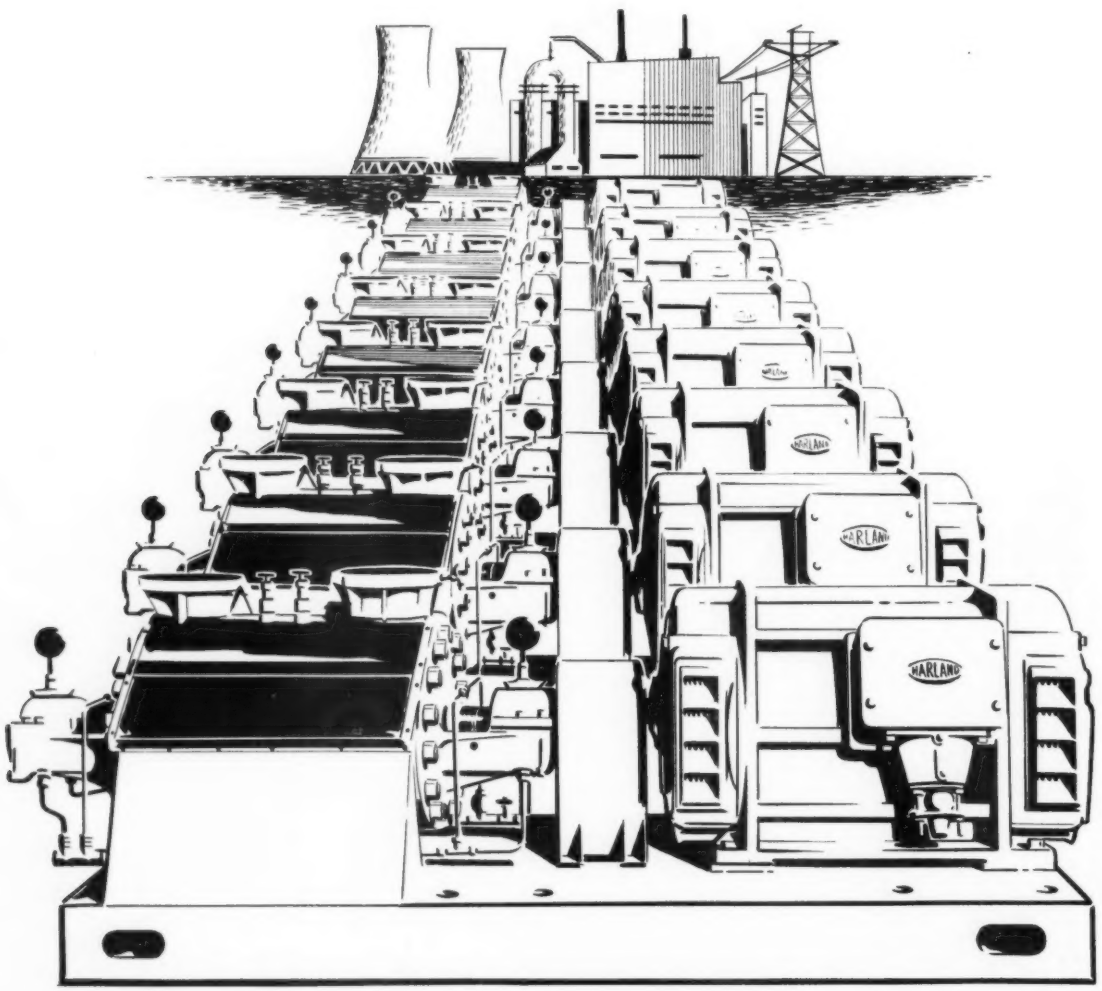

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III

Nuclear Power
THE JOURNAL OF BRITISH NUCLEAR ENGINEERING
JULY 1957 VOLUME 2 NUMBER 15

Heart of the matter

Even if not anatomically the centre of things, the primary coolant circulation pump must be considered the heart of any reactor. In this country we are committed for some years to come to the gas-cooled graphite-moderated plant, and the design and construction of the great gas blowers or circulators is one of the most important parts of the whole. In the size now being built, these units will have to circulate something like 1000 pounds of carbon dioxide a second at a temperature of 350 to 400 degrees F and, although the pressure rise through the impeller is fairly low, the static pressure in the casing will be about 150 pounds per square inch. All this has to be done with the absolute minimum of leakage from the rotating shaft seal and with the maximum of reliability under continuous operation. These blowers absorb something like 10 to 15 per cent of the gross output of the station, so their design is a vital factor in the overall economy of the system. There is every evidence that British engineers have solved these problems and that the new power stations will not be let down on gas circulation.

Perhaps not so spectacular, though just as important, are the high-pressure forced-circulation pumps for the boilers, and here one British firm has recorded a notable achievement by supplying their type of glandless pump for every UK nuclear power station yet built or projected.

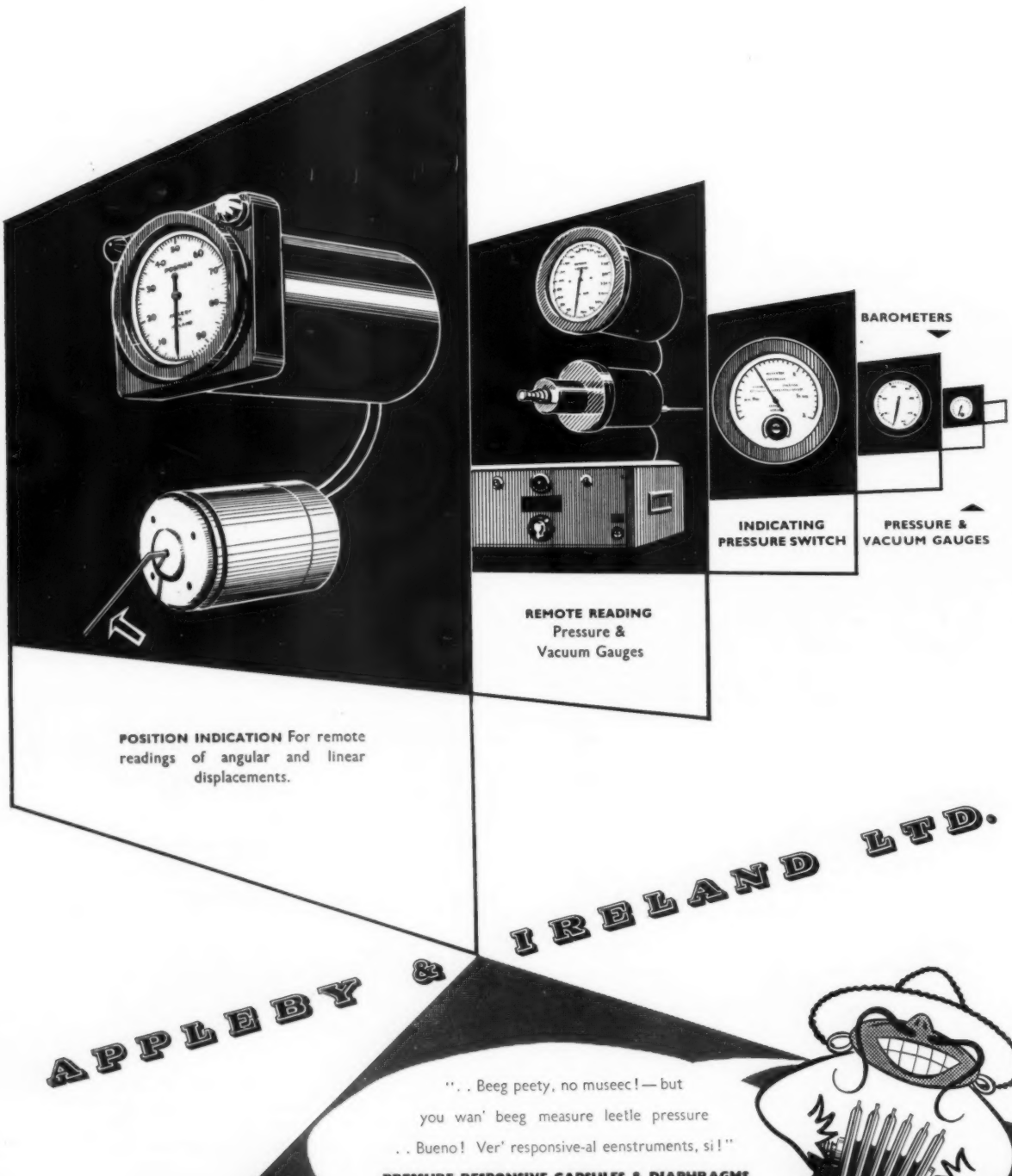
On electromagnetic pumps for liquid metal cooled reactors, Britain seems to be well to the fore and if sodium-graphite, for example, is chosen for one of our Stage 2 reactors, it should not be held up for lack of suitable pumps. It may well be, of course, that the mechanical pump will eventually prove itself superior to the electromagnetic for handling liquid metals and the fact that it has been chosen for the Enrico Fermi Fast Reactor may indicate that the Americans are now confident in their ability to produce mechanical pumps to the required standards of leak-tightness and reliability. Only time will settle this question, but there is no doubt that the electromagnetic pump will continue to be developed for, even if some efficiency is sacrificed, it holds a trump card in having no moving parts whatsoever.

The development of special pumps for nuclear power reactors in this country is at present concentrated among comparatively few firms, most of which have benefited greatly from development contracts from the United Kingdom Atomic Energy Authority. The development of a completely new pump to meet these stringent conditions, or even the adaptation of an established design, costs, however, a great deal and needs skilled engineering and authoritative guidance as to the exact requirements. But it would undoubtedly speed progress if the pump industry could take courage from the tremendous opportunities presented by nuclear power and branch out on its own initiative. It is really the old question of the supply and demand: which comes first? The answer is surely, to be able to foresee the demand and have the supplies ready when the demand materializes.

So far, only the simplest pump problems have been tackled and advanced reactors are in many cases held back for want of suitable pumps. A fully developed mechanical liquid metal pump, for example, is badly needed; the homogeneous aqueous and the aqueous slurry reactors will succeed or fail largely on their pumps; even the pressurized water reactor needs pumps that are not available in this country.

Special pumps for nuclear energy could form a most important export and although one British firm has already scored notable successes in this field, much more could be done by the pump industry. The quickening tempo of nuclear developments, particularly in Europe, is bound to lead to a considerable demand for special pumps and, it should be noted, this will not by any means be confined to the types now being used in British gas-cooled power stations. This is surely a great incentive and challenge to the industry.

See, where you cannot be



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UNITED KINGDOM

Lower load factors needed—Eccles

Britain's programme of nuclear power stations 'is something more than a means of filling the gap occasioned by the shortage of conventional fuels; it is a demonstration and a shop window for all the world to see that Britain is prepared to play, and is capable of playing, the same rôle in the second industrial revolution as she did in the first'. This was said by Sir Josiah Eccles, Deputy Chairman (Operations), CEA, in his Presidential address to the ninth British Electrical Power Convention, meeting in Eastbourne on June 15. The amount of electricity produced now was double that being produced in 1948.

By improved efficiency during the last nine years, we had saved over 31 million tons of coal. The electrical power plants now coming into production would generate nearly one and a half times the amount of electricity per ton of coal used that was generated in 1956.

The large new generators enabled the designer to get much more output from each ton of steel or copper employed in their construction. As an example, in the 200 MW alternators there was only 22½ per cent of the copper and 50 per cent. of the steel per megawatt of output that was used in the 30 MW alternators of a decade ago. Raw copper and iron ore were imports and, hence, the vastly better use of those materials by the designer was not only reducing the real cost of his product but was making a direct contribution to the solution of our balance of payments problem.

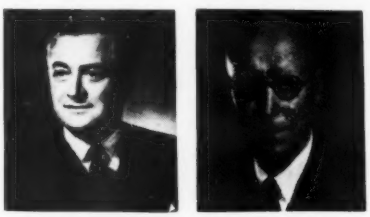
In 1947, the new generating plant brought into service in Britain had an output of only 370 MW. Each year since then they had raised the sights until, in 1956, no less than 1,937 MW of new plant was added to the total. In other words, in each two weeks of 1956, they placed new generating stations in service equal to the full output of the Calder Hall Station!

'It might be asked,' Sir Joseph said, 'that if nuclear energy is so attractive, why not drop all other forms of development and go full out for nuclear electricity? One has to confess that there is considerable attraction in this thought, and, speaking personally, there is no doubt in my mind that nuclear energy will ultimately become the main source of power in this country. But it cannot happen overnight'.

The early nuclear plants would have to be operated at the highest practicable load factors and everything possible would have to be done to ensure that reactors had a useful working life of at least twenty years if the cost per unit of electricity was to come within the competitive range. Since only about 15 per cent. of the national electricity load is continuous, it would not be economically practicable at present to have much more than 20 per cent. of the generating capacity energized by nuclear reactors. When the need to step up this proportion arose, a good deal could be done to flatten the electricity load curve by the extensive adoption of three shift working throughout industry, by extending the use of storage heating and air conditioning and by pumped storage. By that time the capital cost of reactors might be such that they could be operated economically at lower load factors.

John Thompson chairman knighted

The nuclear power industry again features in the Birthday Honours' List. Edward Thompson, Chairman and Joint Managing Director of John Thompson Ltd since 1948 becomes a Knight Bachelor. A knighthood also goes to Frederick Pickworth, of the English Steel Corporation, Ltd, who joined the company as Secretary after its formation in 1929 and is now Chairman and Managing Director. K. L. Stock, Under-Secretary to the Ministry of Power, is awarded the CB.



Edward Thompson (left) and Frederick Pickworth—knighted in the Birthday Honours List

CBE's go to D. G. Sopwith, Director of Mechanical Engineering Research, DSIR; C. M. Vignoles, Managing Director of Shell-Mex and BP; H. W. Grimmitt, Chief Engineering Inspector, Ministry of Power; J. L. Morrison, Professor of Mechanical Engineering at Bristol University; J. G. Pearce, Director of Research, British Cast Iron Research Association; and E. Player, Managing Director of Birmid Industries.

Among the new OBE's are F. A. Rawlings, who is Finance Officer of the CEA; J. T. Tomblin, Superintendent Planning Trials Division of AWRE, Aldermaston; G. Weston, Technical Division of the British Standards Institution; A. Wragg, Chief Metallurgist of Vickers-Armstrong; and S. J. Wrigglesworth, Director and General Manager of Oldham and Sons, Denton.

The following were awarded MBE's: J. A. Drinkley, Development Engineer and Designer-in-Charge of R. B. Pullin & Co., Ltd; H. Lloyd, Chief Experimental Officer of the Metallurgy Division, Harwell; A. J. Smith, Chief of Production Control, Commercial Engineering Factory, EMI Electronics Ltd; and F. W. Townsend Experimental Manufacturing Manager of the Plessey Co Ltd. Finally, BEM's went to T. W. Davies, a sheet metal worker at Marston Excelsior Ltd; A. C. Pincott, Laboratory Superintendent, Turbine Systems Development, Plessey Co Ltd; and D. Spence, site welding engineer at Whessoe, Ltd.

Japan to buy British?

A company for buying nuclear power stations is to be formed by the Federation of Japanese Electrical Industries. This was announced by Mr Koichi Uda, chairman of the Japanese Atomic Energy Commission, arriving in England last month for a ten-day visit. During his stay he discussed the peaceful uses of atomic energy with Lord Mills, Sir Edwin Plowden and Mr Selwyn Lloyd.

The Japanese AEC would not itself be concerned with buying reactors, but the Government might have to provide the company with financial support. On Calder Hall type reactors, Mr Uda said the design was undoubtedly a good one and the Federation would probably be interested in buying a plant of this type. The fact that Britain had a power reactor in operation spoke for itself—in fact, when people talked about power reactors in Japan, they meant the Calder Hall type.

Yearbook for nuclear industry

By 1958 it is expected that current British development work on beryllium metallurgy will have come to fruition and that by that time our techniques of extraction and fabrication will be as advanced as those of any other country in the world. This is stated in an important article by Mr L. Grainger, chief metallurgist of the UKAEA Industrial Group, in the first edition of the NUCLEAR POWER YEAR BOOK AND BUYER'S GUIDE, published last month. Mr Grainger's article is on trends in fuel elements: other review articles deal with nucleonic instrumentation, mining of uranium minerals, zirconium, niobium, liquid metals, nuclear physics, welding, atomic energy and the law, and isotopes. A distinguished panel of authors include Dr Denis Taylor, Dr Alfred Maddock and Mr James Hill, consultant editors of NUCLEAR POWER.

In addition to the review articles, this

500-page reference book contains invaluable technical data and includes what is probably the most comprehensive table of isotopes ever published. Other contents include: full details of the national and international authorities of the world; a Who's Who containing the most important names in nuclear energy in Britain. The Buyers' Guide section includes full details of over 800 British firms, and their products classified under nearly 1000 headings.

AEA centre under way

Now nearing completion in London is the new AEA headquarters on the corner of Lower Regent Street and Charles II Street (see photograph on title page, taken in May). With a floor area of 40,000 sq ft available, it will accommodate the majority of the Authority's London staff, and is due to be opened in February 1958. One of the features will be an information centre, open to enquiries from the public and industry. Access to information held by the various AEA groups will be available, and the centre will be staffed by technical personnel. Copies of all declassified reports will be held there, and the public will be able to enter this part of the building, which faces on to Charles II Street, without a pass.

Russian atom film shown

Shown for the first time in London last month was a Soviet documentary on the industrial uses of atomic energy called *Atoms for Peace*. In full, and very effective, colour, with a commentary in English, it has a running time of 75 minutes. After an explanation of the principle of fission, using animated diagrams, the film gives shots of several reactors in use, including a pool type for the production of radioisotopes—this sequence contains a photograph taken by Cherenkov radiation—and a heavy water reactor. There is an impressive display of remote control equipment and mechanical manipulators, with delicate and interchangeable jaws. Other sequences show the principle of the cyclotron and give pictures of a linear accelerator, a 600,000 eV cyclotron and the 10 GeV proton synchrotron, then still under construction.

Quite a large part of the film is devoted to industrial uses of nuclear energy, including irradiation of polythene, fault detection, density measurement, tracer techniques, etc. Medical uses are demonstrated by the work of the Oncological Research Institute.

Chief director of the film was D. Bogolyepov and among the consultants were V. Veksler and A. Alikhanov, members of the USSR Academy of Sciences.

The film is available on hire from Photo Films Ltd, 18 Greek Street, London, W1, and further details can be obtained from them.

Atomic-hydro station

Site investigations for further Central Electricity Authority power stations are continuing and in addition to the one at Dungeness, Kent, it seems certain now that North Wales will be included in the next round of stations. This project is particularly interesting since the nuclear power station will be designed to integrate with the Blaenau Ffestiniog pumped-storage hydro scheme, work on which was recently restarted, having been suspended for some time due to the credit squeeze. The site of the nuclear plant will not, of course, be at Blaenau since it is not on the coast. A position on Cardigan Bay near Aberystwyth is more probable and test borings along this coast have been made at various points.

The position at Dungeness is that the site has been deemed suitable for a power station of some kind but it is still not certain that it will be a nuclear one. What has, however, been settled is that Dungeness will be the British terminal of the under-channel power line linking the grids of the Central Electricity Authority and Electricité de France.

At the Hankley Point, Somerset, site, the public enquiry has been held and a decision is awaited. It now seems likely that the installed capacity there will be 450MW: in the following stations the output will possibly be 500 MW.

Meanwhile, the second public inquiry into the proposed Hunterston site for the South of Scotland Electricity Board's first nuclear power station, the contract for which was let to the GEC Simon-Carves Group six months ago, has been held at Largs under the chairmanship of Mr H. R. Leslie. Speaking for the Board, Mr A. Thompson QC said if construction at Hunterston did not start this summer, the Clyde Valley area would be importing English electricity by 1961. Evidence previously presented at the first inquiry under the late Sir Randall Philip was accepted by Mr Leslie who will now submit his report to the Secretary of State for Scotland.

Fusion talks at Harwell

Cooperation in developing thermonuclear power was the theme of a three-day conference held at Harwell at the end of last month. Attended by representatives from the CEA, industry, interested Government departments and 25 observers from the US AEC, a report on British and American progress to date was given on a classified basis, and no report will be published. A large number of firms were asked to assist in British plans for the peaceful applications of thermonuclear power. Among the companies which attended the conference were AEI—John Thompson, BTH, English Electric, GEC, Hawker Siddeley, Head Wrightson, Nuclear Power Plant Co, C. A. Parsons, Plessey, Richardsons Westgarth, Simon-Carves, and Vickers Nuclear Engineering.

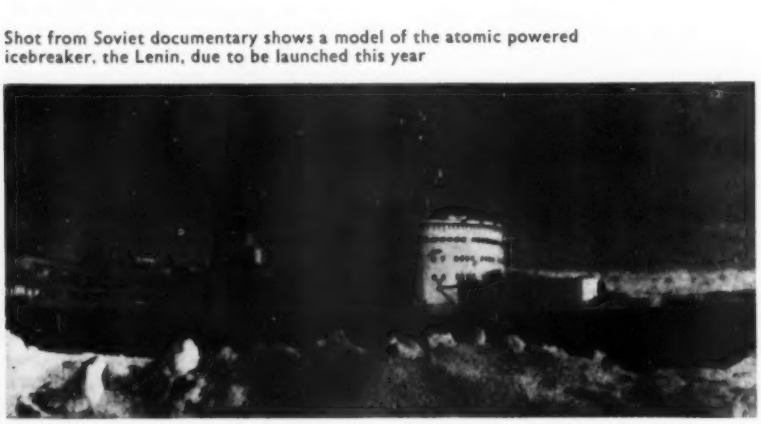
Britain leads the world—Hahn

At Cambridge this month an honorary Doctorate of Science was conferred on German physicist Professor Otto Hahn, who is President of the Max Planck Institute at Göttingen and a member of the German Atomic Energy Commission. Hahn's work with Lise Meitner and F. Strassmann finally culminated in the discovery of uranium fission a few months after war had broken out in 1939.

Speaking of nuclear energy, Professor Hahn thought Britain led the world in its development for peaceful uses. Of the hydrogen bomb tests he said 'I do not think the radioactive dust is dangerous yet, but it will be if countries continue the tests.'

During his three-day visit to this country, the professor was also elected a foreign member of the Royal Society.

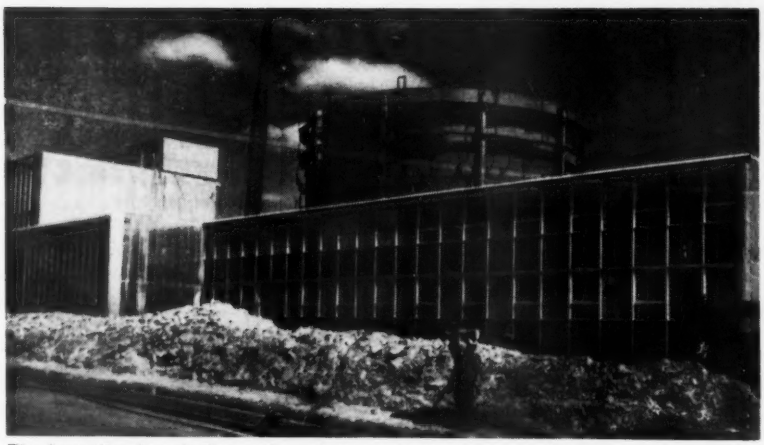
Shot from Soviet documentary shows a model of the atomic powered icebreaker, the Lenin, due to be launched this year



DENMARK

PLUTO for Roskilde

The Danish Atomic Commission have ordered a British research reactor. This is to be a heavy-water-moderated high-flux machine similar to PLUTO at Harwell and DMTR at Dounreay. It is to be supplied by Head Wrightson Processes Ltd, London, who will be responsible for the design, engineering procurement and erection of the reactor at the Danish research centre at Roskilde. This will be the fifth reactor of the DIDO/PLUTO type built by Head Wrightson and it is understood that a sixth is shortly to be ordered from Germany. The Danish reactor will be used for materials testing and high-flux irradiations. It is planned to come into operation before the end of 1959. Enriched fuel will be supplied by the UKAEA from the Dounreay fuel plant.



The Australian Atomic Energy Commission research centre near Sydney is now making rapid progress. AAEC photo dated March this year shows reactor laboratories with the HIFAR (High Flux Australian Reactor) sealed steel building rising behind. HIFAR is almost identical to Harwell's DIDO. Other site facilities include chemical and engineering laboratories and a sodium loop building

FRANCE

New reactors planned

Further details were released last month by the Commissariat à l'Energie Atomique on France's new 5-year plan, first announced last April by Secretary of State Georges Guille. (*Worldview*, May.) Like other countries, France's nuclear effort is limited to a great extent by the present shortage of trained men and the CEA report states that the atomic industry—national and private—needs 5,000 engineers this year and from 12,000 to 15,000 in 1961. The Commissariat is making strenuous efforts to encourage the right type of technical education and a year ago it set up, in conjunction with the Ministry of Education, the Institut National des Sciences et Techniques Nucléaires. Already, courses in nuclear subjects have been organized at French universities and technical colleges.

Striking figures are quoted for uranium metal. The present price for uranium minerals is about 12,000 francs per kilo for concentrates, with a further 5,000 francs for reduction to metal. Plant extensions at Le Bouchet and elsewhere now in course of construction will bring these prices down to about 10,000 and 4,000 francs respectively. It will be noted that these figures for metal correspond to about £17,000 and £14,000 a ton respectively.

The report mentions several new reactors now building: PROSERPINE — a zero-energy homogeneous reactor using plutonium sulphate in ordinary water, at Saclay; EL3—Saclay's new high-flux (10^{14}) reactor, due critical later this year; MELUSINE and TRITON, two 1 MW pool reactors, the former at the new Grenoble centre and the latter at Fontenay-aux-Roses. Both are due to be ready next year.

In the design stage are: a second high-flux reactor with highly enriched U; a gas-cooled beryllium-moderated natural U reactor; a medium power very-high-temperature gas-cooled reactor for gas turbine applications; a zero-energy plutonium fast breeder; a sodium-cooled thermal reactor moderated by graphite or beryllium, to be built around 1961.

On France's submarine project, the CEA report discloses that the decision to build the ship was taken two years ago. As already reported, the prototype will use natural U and pressurized heavy water but there is no intention of perpetuating this arrangement after enriched fuels become available in sufficient quantity.

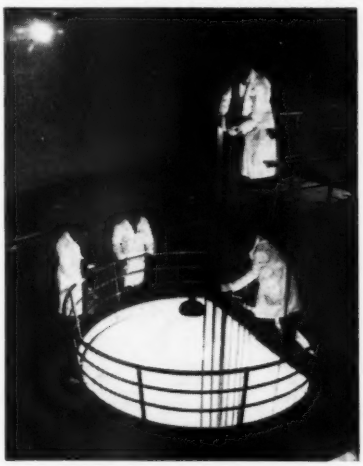
Referring to Electricité de France's power programme, it is stated that the first plant, EDF1 at Avoine, near Chinon, should be in operation with 60 MW in 1959. Other, larger, stations will follow at intervals of 12 to 18 months. The report emphasizes that France should make provision for enriching her own uranium, even if it costs more than imported American material. A final decision on whether or not to build a diffusion plant is expected to be taken later this year. Meanwhile, France's nuclear economy is firmly pinned to the plutonium system and every effort is being made to overcome the difficulties involved in using it as a fuel.

NETHERLANDS

Pool reactor starts

Amsterdam's international atomic energy exhibition *Het Atoom* was opened officially on June 28 by Prince Bernhard in the presence of Queen Juliana. Highlight of the show will probably be the operating pool reactor supplied by AMF Atomics in cooperation with Mitchell Engineering of London. The reactor reached criticality on May 24 and will be on view throughout the run of the exhibition, at Schiphol airport until September 16.

During the four days preceding the opening of *Het Atoom* the OEEC information conference on *Nuclear Energy for Management* was taking place in the Royal Tropical Institute. Some three hundred industrialists from 13 European countries and the United States were present at the conference which was a follow-up to the successful one held by OEEC in Paris last April. Distinguished speakers included: M. M. Berthelot (Saclay), J. C. Duckworth (British CEA), Dr K. H. Hardy (Springfields), Dr L. Kowarski (OEEC consultant), Dr W. B. Lewis (Atomic Energy of Canada), Prof Leander Nicolaides (Chairman of OEEC Steering Committee), Dr C. A. Rennie (Harwell), Einar Saeland (JENER) and Harry West (AEI-John Thompson).



Last of the 25 U-235 fuel elements is put in place in the Dutch pool reactor

UNITED STATES

Reports of the Plowden/Strauss talks in Washington last month on information exchanges under the 1955 Bilateral indicate that both sides eventually agreed to tell more than they had originally intended. Apart from the fact that agreement had been reached on 'a wide range of subjects,' no details of the talks were released, but on his return to London after his session with AEC chairman Strauss, Sir Edwin Plowden told reporters Britain had agreed to give the Commission full details of all Calder Hall developments up to last January. Just why this date was chosen was not made clear but Sir Edwin said the whole question of information exchanges would be reviewed again in the Autumn.

The AEA chairman declared that it was not true merely to say that we had obtained submarine information in exchange for Calder Hall: we would give and get a lot more than that. He said we had a full exchange on fast breeders and there would also be cooperation on homogeneous, sodium-graphite and liquid-metal-fuel reactors. It is probable that information on the Shippingport pressurized water reactor is also included in the agreement.

As to the submarine reactor, it is not known if this was the subject of the Plowden/Strauss talks but later in the month Rear Admiral Hyman (Nautilus) Rickover, accompanied by Rear Admiral A. M. Morgan and Mr I. M. Mandill, arrived in London for talks with Admiralty representatives including Rear Admiral G. A. M. Wilson. No statement was issued but it might be assumed that the talks were indeed the long-awaited exchanges on atomic submarines.

The difficulty about Anglo-American atomic exchanges has of course been the different attitude in the two countries towards commercial security. Both here and in America atomic energy has been developed almost entirely with taxpayers' money. In the United States the Government's policy has been, crudely, to reward the taxpayers simply by letting them have the information obtained with their money provided military security is not involved. Here, on the other hand, the Atomic Energy Authority aims to make some money for the taxpayer by asking payment for any commercially valuable information obtained at public expense. Thus transatlantic exchanges are not easy. It would be absurd, for example, if an American firm could obtain for nothing information which a British company would have to pay for.

The United States is known to be particularly interested in Calder Hall's descendants—the new CEA stations. Here the situation is much more involved since the Atomic Energy Authority has had little to do with the designs apart from acting in an advisory capacity. In such cases, it is presumably up to the firms involved to make their own arrangements about their own designs.

Isotopes save millions

Use of radioisotopes is estimated to have saved American industry not less than $M300 and possibly as much as $M500 during the year 1956. The biggest single saving was in oil well stimulation—from $M120 to $M180. The next biggest was, curiously enough, in cigarette density gauging. Some 2,235 nucleonic density gauges—many of them of British manufacture—were licensed by the AEC and between them they saved the American tobacco industry between $M35 and $M58 last year. These figures were produced for hearings before the Joint Congressional Committee on Atomic Energy last February and they are now published in a 250-page report presented last month to the United Nations Economic and Social Council by Secretary-General Dag Hammarskjöld.

The report—*Economic Applications of Atomic Energy: Power Generation and Industrial and Agricultural Uses* — is probably the most comprehensive statement yet on the present status of nuclear energy developments in the Atomic Big Five—USA, UK, USSR, Canada and France. It includes detailed replies from these countries to a studied questionnaire sent them by the UN. Of particular interest are some details of two new Russian power plants known only as 'Project 1' and 'Project 2,' which are apparently now under construction. One of these is a 390 MWE (net) plant with two pressurized water reactors. The other is a 375 MWE (net) two-reactor station with graphite-moderated, water-cooled units. As in all Russian information the big question left unanswered is 'where are they?'

IAEA statute ratified by US

US participation in the International Atomic Energy Agency was approved by the Senate last month. Voting was 67 to 19, well over the two-thirds majority needed for ratification. As adopted, the resolution contains an 'interpretation and understanding' providing that any amendment to the agency's basic Charter shall be submitted to the Senate for its advice and consent, as in the case of the initial ratification. If the Senate should withhold its consent, the US would cease to be a member of the agency. Legislation needed to implement American participation will be considered jointly by the Senate Foreign Relations Committee, the Foreign Affairs Committee and the Joint Atomic Committee representing both legislative branches.

Before the final vote, the Senate rejected a resolution proposed by Senator John O. Bricker (Republican, Ohio), who opposed American participation. Rejected amendment would have meant that the US could make special fissionable materials available to the agency only with the consent of Congress. Senator Theodore F. Green, chairman of the Foreign Relations Committee, told the Senate that the amendment was not only completely unnecessary but would 'play directly into the hands of the Soviet Union.'

YUGOSLAVIA

Hope for small GC reactors

Choice Frontier is a new concept in nuclear economics introduced by United Kingdom AEA economic adviser J. A. Jukes in a paper presented to the XIth Sectional Meeting of the World Power Conference held in Belgrade last month. Mr Jukes produced a graph by means of which, knowing the local price of gas or diesel oil and the expected load factor, it is possible to see at a glance whether a nuclear power station of 10 or 20 MW would be more economic than a diesel installation of the same output. The limiting lines he called choice frontiers. He thought gas-cooled graphite moderated reactors could be made with outputs down to 20 MW and although the capital cost would be certainly high they might still be economic in certain circumstances. Natural uranium could be used, but a great improvement in economy would result if a degree of enrichment in the form of spikes was available. An interesting paper by W. E. Shoupp and A. R. Jones of Westinghouse described a range of pressurized water reactors the firm have projected suitable for underdeveloped countries. Based on the Shippingport PWR and incorporating similar features, these reactors would be in standard outputs of 11·5, 15, 68 and 143 MWE. In the biggest model the head closure of the pressure vessel is of an unusual design although the vessel itself strongly resembles the Shippingport one.

Speaking on small power plants, United States AEC Deputy Director of Reactor Development, Louis Roddis, included some details of the Los Alamos LAPRE-1. Mr Roddis said it used a plutonium solution of extreme corrosiveness. All reactor parts were in stainless steel and gold plated as well. Even so, a small scratch in the plating caused during assembly early in 1956 led to a hole through a heat exchanger tube in a matter of five hours. The reactor was rebuilt and tried again last October but this time a leak occurred after only a few minutes' operation and so far it has not been possible to restart the experiment. Despite these difficulties however, Mr Roddis believed that the system had possibilities for small plants.

ELECTROMAGNETIC PUMPS FOR REACTORS

A survey by W. B. WOOLLEN, BEng(Hons),

Atomic Energy Research Establishment, Harwell

LIQUID METALS are now either being employed or seriously considered as coolants for fast and thermal heterogeneous and homogeneous reactors. Interest in liquid metals was aroused at an early date because it was realized they could be circulated by electromagnetic pumps, containing no moving parts, gaskets or glands to cause operational troubles. The portion of the pump containing the liquid metal could be hermetically sealed by welding or similar reliable leakproof process. It was natural, therefore, that the early liquid metal technologists immediately turned their interests to the development of e.m. pumps. Initially, mercury was favoured as the liquid but for reasons to be stated later, this was dropped in favour of the considerably more attractive sodium.

Prior to the advent of nuclear reactors there had been a little work on electromagnetic pumps but this was confined to small units such as those used in metal foundries and similar applications[10]. The usual application was the moving or lifting of high temperature liquid metal over short distances and no e.m. pump was developed which could be used for circulating a liquid metal as a coolant. It is interesting to note, however, that the first suggestion for the use of an e.m. pump in a coolant circuit was in a patent taken out by Einstein and Szilard in 1928[11]. They proposed that sodium-potassium and a gas should be used in a refrigerator cycle, the metal being pumped by an annular induction pump. It is not clear whether such a proposal was carried out and there are no details of either the construction or performance of the pump.

Liquid metals have been proposed for all types of reactors including the boiling type, the main reason for their selection being their high thermal conductivity, thermal and radiation stability. The desirable properties of a reactor coolant can be summarized as follows:

1. A high boiling point, i.e. low vapour pressure at the operating temperature
2. A low melting point
3. Stability at high temperature
4. Stability under radiation
5. Low neutron-capture cross section
6. Little long-term induced activity
7. Good heat transfer
8. Non-corrosive to structural materials
9. Cheap and readily available
10. Low pumping power
11. Little other hazard, i.e. toxicity or fire

There are no coolants available which satisfy all these requirements but a few liquid metals meet most of the more important ones (Table I). With water there are problems of high pressures and corrosion, while heat transfer and pumping power are difficulties with gas coolants. These limitations become particularly serious in the design of a fast neutron type of reactor.

Of the many elements classed as liquid metals, several such as cadmium, caesium, gallium, magnesium, tin, etc. require no further consideration at this stage for various reasons such as cost, corrosiveness, high neutron cross section, etc. The six liquid metals that are of interest are the three alkali metals—sodium, potassium and lithium—and the three heavy metals—lead, bismuth and mercury together with their alloys.

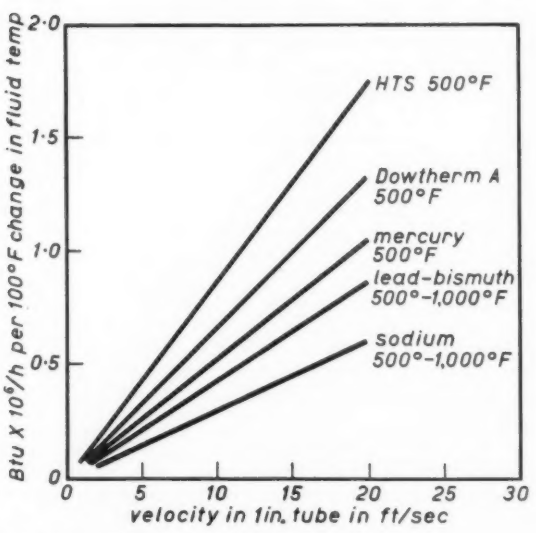


Fig 1 Comparison of fluids for heat transport

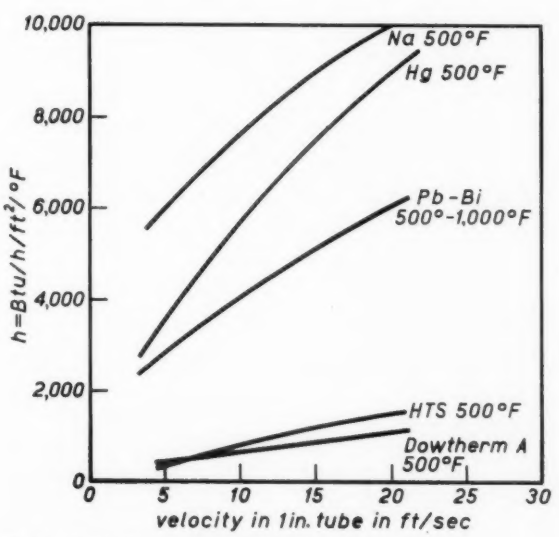


Fig 2 Comparison of fluids for heat transfer

The chief interest in potassium lies in the fact that if it is added to sodium, a eutectic can be formed with a melting point of −12°C. It is unlikely that the eutectic would be used as a reactor coolant since alloys containing a smaller proportion of potassium are molten at room temperature. By reducing the percentage of potassium in the alloy, its physical properties are improved and the capture cross section, and because of its property of dissolving in appreciable quantities fissionable and fertile material. Bismuth, however, is fairly corrosive, and in a reactor alpha-active polonium is produced which has a half life of 138 days. Pure lead, on the other hand, will have very little induced activity and is probably less corrosive than bismuth.

Table I The more important properties of liquid metals

	K	Na	Li	Hg	Bi	Pb	NaK (Eutectic 76%K)	PbBi (Eutectic 55%Bi)
Melting point °C	64	98	179	−39	271	327	−12	125
Boiling point °C	760	883	1317	357	1477	1737	784	1670
Density at 400°C g/cc	0·75	0·85	0·49	12·9 (300°C)	9·91	10·51	0·775	10·19
Specific Heat at 400°C cal/g	0·183	0·306	1·0	0·032 (300°C)	0·035	0·037	0·21	0·035
Thermal cond. at 400°C cal/sec/cm²/°C	0·096	0·170	0·09	0·033 (300°C)	0·037	0·038	0·064	0·028
Electrical resistivity at 400°C microhm/°C	35	20	45 (230°C)	127 (300°C)	134	98	47 (200°C)	123
Thermal neutron capture X Section. Barns	2·5	0·56	65	430	0·033	0·17	1·7	0·17
Approx Cost per lb	20/−	1/−	80/−	26/−	18/−	1/6	15/−	10/−

cost reduced. Lithium and mercury are included in the table, although they have high cross-sections, because they both have isotopic forms with low cross-sections (Li-7 0·033 barns and Hg-204 0·34 barns). If an economic method of isotope separation could be found they are potential coolants. Mercury is highly toxic and expensive but because of its relatively low boiling point it probably offers the possibility of a boiling liquid-metal-cooled reactor. It is the only common liquid metal which is molten at room temperature and has been used by the GE in the USA with considerable success to replace water in a portion of a conventional coal-fired boiler. Lithium is probably the best heat transfer fluid although handling and corrosion problems may be considerable. Bismuth has always been attractive because of its low neutron

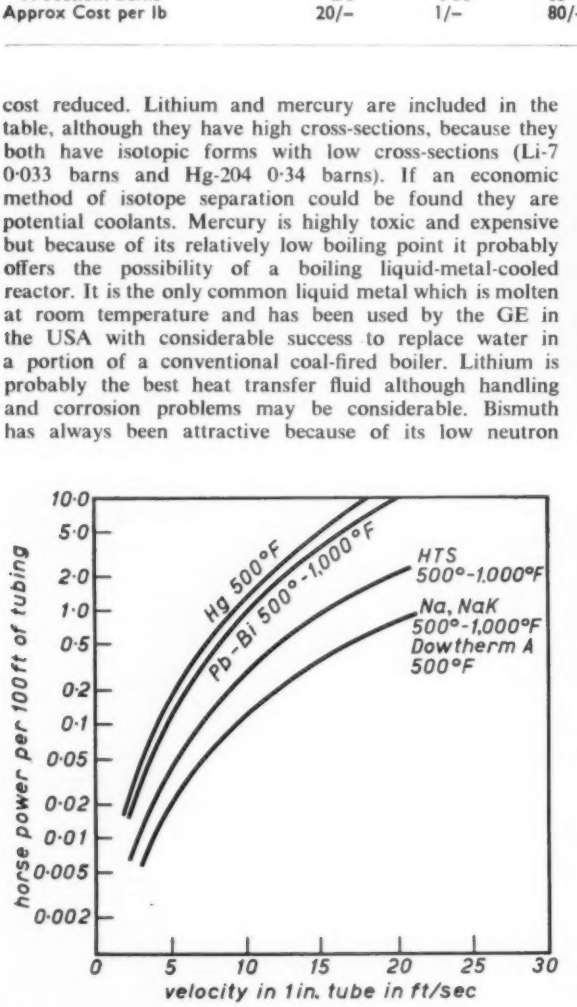


Fig 3 Comparison of pumping power for various fluids

Fig 4 Fleming's left-hand rule

As a result of the early deliberations, it was considered that sodium would be the best all-round coolant for reactors and so most work on liquid metals has been confined to it. Initially, and in particular for laboratory work, the sodium-potassium alloy was used because of its low melting point, but as the technology has been improved, metals with higher melting points have been accepted. Although sodium has a very high induced gamma-activity there are no isotopes produced with very long lives (Na-24 has a half life of 14·8 h). More recently, considerable work has been initiated both in the USA and UK on the use of bismuth in a liquid fuel type of reactor[12].

A rough comparison of the heat transport, heat transfer, and pump power of a number of coolants is given in Figs 1, 2 and 3, and the obvious superiority of liquid metals is clear. Fig 1 must be interpreted with care since the heavier the fluid the lower the maximum permitted velocity.

Types of e.m. pump available

The pumping force in all e.m. pumps is produced by the interaction of a current flowing through the liquid metal and a magnetic field at right angles to it—exactly the

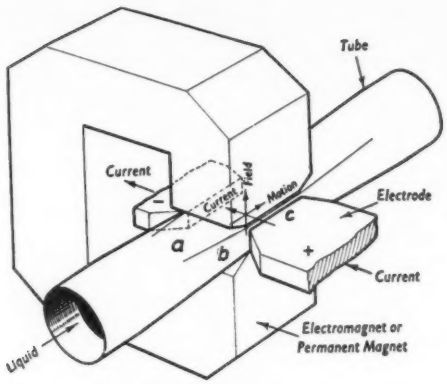


Fig 5 Principle of the simple d.c. pump

principle used in an electric motor. The motion of the fluid is then in the third direction and can be ascertained by the well-known Fleming's Left Hand Rule (Fig 4). The liquid metal is passed through the pumping duct of the pump across which are produced the current and magnetic field. There are two major classes of e.m. pump, the induction type and the conduction type. In the former the current is produced in the liquid metal inductively from coils outside the pumping duct, whereas in the conduction type the current is fed into and taken out of the duct by busbars attached to it. In both cases the field is produced by core assemblies placed adjacent to the duct. The conduction type can also be either of the a.c. or d.c. form, depending upon the type of current and field employed. The induction type pump by definition must be an a.c. form and the current and magnetic field must in all cases be substantially in phase with each other. The following is a list of the more important types of e.m. pump.

CONDUCTION CLASS

1. d.c. or Faraday type
2. a.c. type

INDUCTION CLASS

1. Flat Linear Induction Pump (FLIP)
2. Annular Linear Induction Pump (ALIP)
3. Spiral Induction Pump (SIP)
4. Rotating Magnet Induction Pump

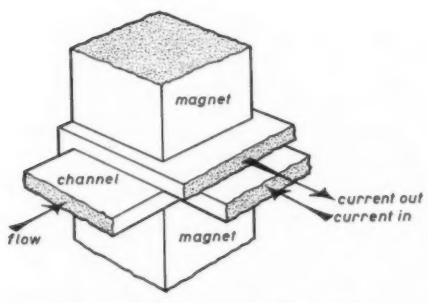


Fig 6 ' Armature reaction ' compensated d.c. pump

Most development so far has been on d.c. and a.c. conduction types and on the FLIP. Some work has been done both here and in America on spiral induction types and more recently some effort has been concentrated on the annular induction pump. The rotating magnet type of pump has received almost negligible effort in this country, despite the fact that commercial units are available in the USA. Alternating current pumps are not necessarily confined to 50 cps and Blake[2], in particular, has pointed out the advantage in certain cases of running at very low frequencies.

CONDUCTION PUMPS

Direct current types

This is the simplest form of e.m. pump but in order to achieve a reasonable efficiency some elaboration is necessary. In its simplest form (Fig 5), it consists of a rectangular duct into and out of which the liquid metal is fed via section changers from the main pipework. Copper

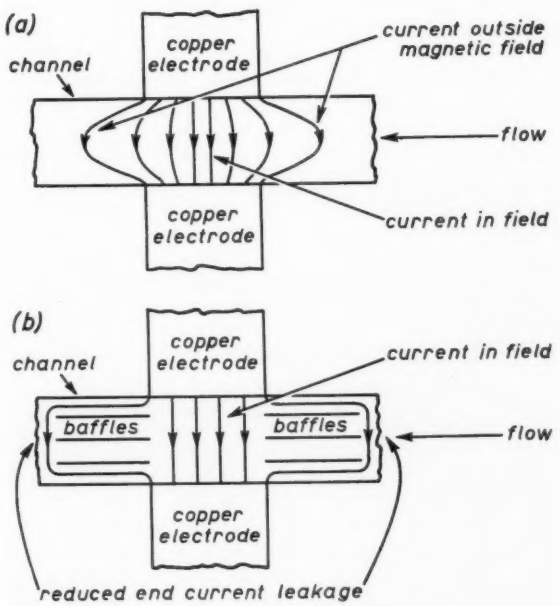


Fig 7 End current leakage (a). How it is reduced (b)

busbars are attached to two opposite sides by which the large current is fed through the liquid metal. Magnet poles are placed adjacent to the other pair of sides in order to produce a magnetic field at right angles to the current.

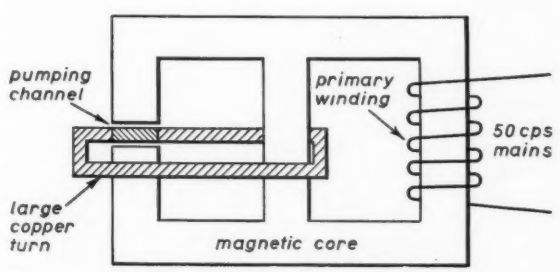


Fig 8 The a.c. conduction pump combined with transformer

Elementary equations for the d.c. type of pump are given below:

Pressure rise $P = \frac{B\,I_F}{10\,b}$ dynes/sq. cm.

Back e.m.f. $E = \frac{B\,a\,V}{10^8}$ volts

Applied voltage $V = E + I_F\,R_F$ volts

Volume flow $Q = V.\,a.\,b$ cc/sec

Current input $I = (I_F + I_W + I_L)$ amps

Power input $W_I = VI$ watts

Power output $W_O = PQ10^{-7}$ watts

B = flux density across the fluid in gauss

I_F = current in fluid in amps

V = velocity of fluid in cm/sec

a, b, c = internal dimensions of the channel

R_F = resistance of fluid between electrodes in ohms

I_W = current in channel wall in amps

I_L = current leaking out of ends of pump in amps

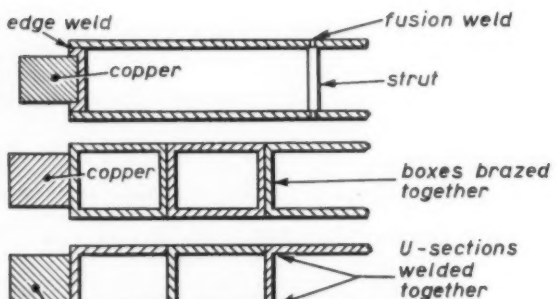


Fig 9 Some possible methods of pump channel construction

Armature reaction

In the simple design illustrated, no attempt is made to neutralize the magnetic effect of the main current flowing in the liquid metal. This magnetic field disturbs the main magnetic field in the gap and causes distortion of the current in the liquid. This effect, known as 'armature reaction', was first investigated by Woodrow. It can be eliminated by means of a compensating winding, similar to those used in d.c. motors, by returning the current which has passed through the liquid metal and channel walls back along a flat conductor sheet adjacent to the channel (Fig 6). This conductor is designed so that the magnetic field of the current in it cancels out that of the current in the liquid metal and channel walls. If, however, the field in the gap produced by the main current is low in comparison with the main field, it is possible that compensation will not be necessary. Compensation must however be used in virtually all sizes of d.c. pump for use with sodium.

End effects

The effective resistance of the liquid metal in the pump channel is higher due to the fact that its motion in the magnetic field produces a back e.m.f. This does not exist in the channel walls and is reduced considerably in the liquid metal ahead of and behind the channel. The current fed in from the electrodes therefore partially prefers to use

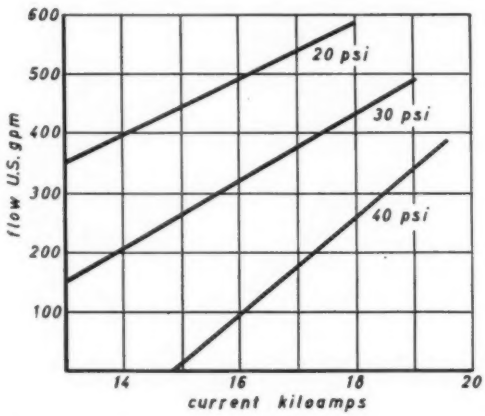


Fig 10 Characteristics of the EBR1 primary pump

these paths in preference to the main one (Fig 7a) and some means of reducing this end leakage must be adopted if a pump of reasonable efficiency is required. There are two ways of reducing end leakage—by baffles in the liquid metal (Fig 7b) or by suitable shaping of the pole pieces at both ends of the pump. The baffles are placed so that the paths for the current leaking out of the ends of channel are considerably longer than they would otherwise be. The end leakage current is therefore reduced.

Power supplies

There are two major problems with d.c. pumps—the connexion of extremely heavy busbars to a relatively thin unsupported channel (discussed later) and the generation of the necessary low-voltage high-current supply. Large pumps require currents approaching 100,000 amps at voltages of approximately one volt. It is impractical to use rotating machines to supply this low voltage owing to the commutator brush drop of about one volt. Even 'conventional' homopolar generators suffer from the same defect but considerable work has now been carried out both in the UK and USA on liquid metal brush homopolar generators. The American version developed at the Argonne National Laboratory[13] employs a tubular shaped generator which is completely drowned in sodium-potassium, connexions being taken from the two ends. The version developed at Harwell[14] is of a more elaborate nature employing two specially shaped channels filled with mercury as the 'brushes', one side of which is stationary and the other attached to the ends of the rotating member. A design study of an improved version of this machine is being carried out for AERE by Brush Electrical Engineering Co. Homopolar generators with liquid metal brushes, when

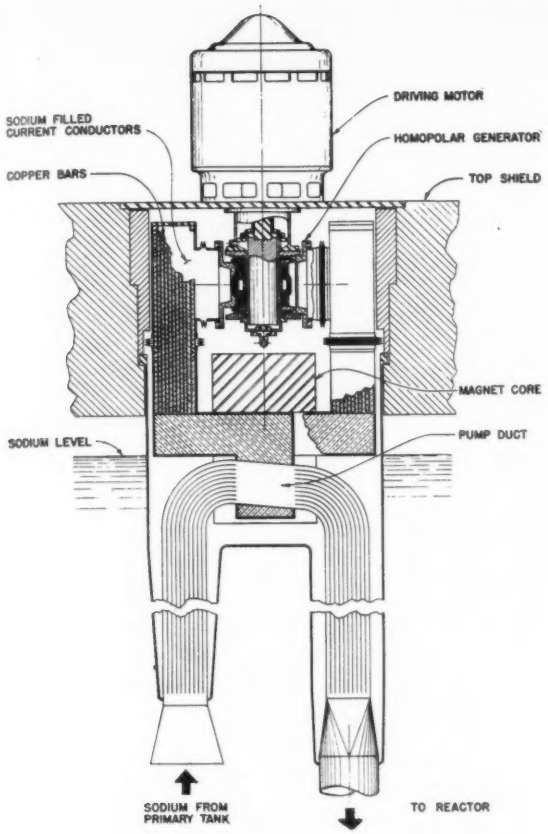


Fig 11 The EBR2 d.c. pump with its homopolar generator

satisfactorily developed, should be reliable low voltage sources of very high currents with efficiencies approaching 90 per cent. It is hoped that other uses will be found for these machines.

Alternating current types

In order to avoid the difficulty of power supplies with d.c. conduction pumps, particularly those suitable for laboratory use [15, 16], the field and current supplies come from a transformer. In most cases, in order to make the complete unit as compact as possible, the transformer is combined with the pump (Fig 8). The efficiency of this type of pump is lower than the d.c. type, even in the case of large units, owing to eddy currents and skin effects.

INDUCTION PUMPS

The most promising type of e.m. pump is the induction variety, of which there are several versions. Unfortunately its efficiency when pumping the heavy metals is extremely low. The main advantage lies in the fact that large currents are not fed into and out of the pump by heavy busbars attached to the pump channels and special supplies are unnecessary. In the majority of cases the induction pump functions in the same way as an induction motor with the rotor replaced by a continuous sheet of liquid metal contained in a pumping duct. Multiphase coils placed adjacent to the duct produce a forward travelling field which in turn produces eddy currents in the liquid metal. These react with the field to produce the required pumping force.

Some of the most successful induction pumps are those which have been made by English Electric Co for the Dounreay Fast Reactor[17] and by the General Electric Co in the USA. Both are of the flat linear induction type (FLIP) and have been made in considerable numbers. Recently more attention has been given to the annular version of this pump (ALIP)[18]. There are two reasons for this; (a) the efficiency of the ALIP type is slightly higher than that of the FLIP type due to the improved current paths in the liquid, (b) the ALIP avoids the rather weak flat sides associated with the FLIP.

One of the limitations of the FLIP and ALIP types is the relatively low head produced. This can be improved in certain circumstances by introducing a spiral baffle into the pump so that the liquid travels down a long path[19]. The main objection to the Spiral Induction Pump (SIP) in comparison with other induction types is that, like the conduction pumps, it is sensitive to the condition of wetting in the pump duct.

There are also other possible types of e.m. pump, some of which have received a certain amount of development. Probably the most interesting is the rotating magnet type, since it avoids the busbar and supply troubles associated with d.c. conduction pumps and also some of the limitations inherent in the induction type. The only available pumps of this type are those marketed by the Findlay Corporation in the USA.

Manufacturing Problems

The most difficult problem encountered during the development of e.m. pumps has been the manufacture of the pumping duct, which must be attached to the main circuit via diffusers. Channels for the early FLIP and d.c. pumps were approximately 8in. by $\frac{1}{2}$in. in section and constructed from 0·020in. stainless steel sheet. The sides were made from U-section and edge welding was employed throughout. Specially shaped end-pieces were used for welding the

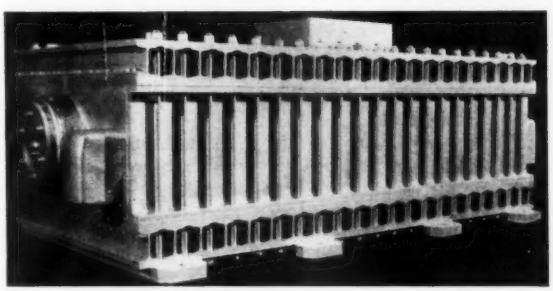


Fig 12 An EBR2 secondary circuit pump

channel to the fabricated section-changers at each end. The channels were unable to withstand any appreciable differential pressure and relied upon the magnets for support. More recently considerable thought has been given to the design of self-supporting channels of larger cross-section, capable of withstanding test pressures up to 250 psi and constructed so that all welds could be X-rayed[20]. Even with these larger channels, wall thicknesses are limited to approximately $\frac{1}{8}$in. for electrical reasons. Various forms of construction are shown in Fig 9. In order to avoid the special junction pieces at the end of the channel considerable development has been carried out on the forming of a complete duct and channel from one piece of tube, but with this form of construction it is difficult to make the tube self-supporting. In considering these problems it must be borne in mind that the thin-walled channel may be

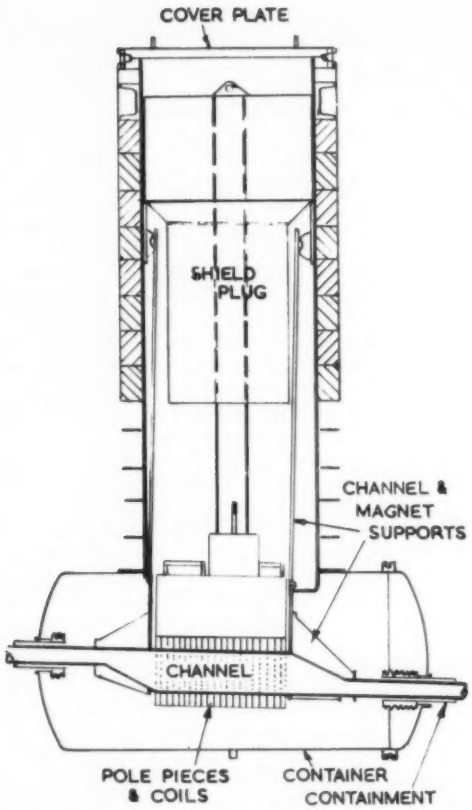


Fig 13 An English Electric FLIP for the Dounreay Fast Reactor

operating at a temperature approaching 300°C and with later designs this may be considerably higher. Furthermore, if there is any danger of the winding giving trouble it must be arranged so that it can be removed remotely, owing to the induced activity. This is very well illustrated in the case of the Dounreay Fast Reactor pump[17].

Associated with the problem of the channel manufacture is that of attachment, in the case of the conduction pump, of the large copper busbars. These have to be fixed to the smaller sides of the channel and, in sodium pumps which have stainless steel channels, this is usually done by furnace brazing. The coefficients of thermal expansion for copper and stainless steel are both close to 17×10^{-6} per °C and little trouble is experienced due to thermal cycling. With bismuth, however, ferritic nickel-free steel must be used and its coefficient of thermal expansion, 14×10^{-6} per °C, is sufficiently different from that of copper to cause some concern about the effect of thermal cycling on the bond between copper and steel. It must be remembered that this joint has to operate considerably above the temperature at which copper begins to scale seriously. Normally the copper busbars are protected by aluminium spraying or are contained in an inert atmosphere.

In the case of d.c. pumps there are few electrical problems but in the case of induction types there are difficulties in operating electrical windings in close proximity to a hot radioactive liquid. There are two main approaches to this problem, both of which have been considered in detail. In one system, the heat generated in the windings in the slots of the magnetic cores is allowed to flow into the liquid metal in the channel; alternatively, the heat is removed either by air or water flowing in holes behind the slots. In the latter case thermal insulation must be placed between the magnetic cores and the channel, whereas in the former the windings must operate at a higher temperature than the liquid metal. Initially Class 'B' electrical insulation was employed, but this has been superseded by Class 'H'. Even this higher temperature electrical insulation with its hot spot temperature limit of approximately 180°C does not completely solve the problem and so considerable development is being carried out. The effect of operating Class 'H' insulation in inert gases is being investigated[21]. Some tests have been carried out on effects of radiation on various insulations[22] but considerably more work requires to be done. It is probable that

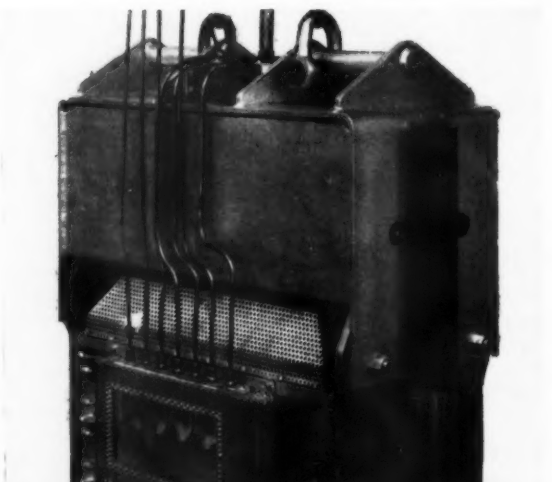


Fig 14 How the DFR FLIP stator clamps the pump duct

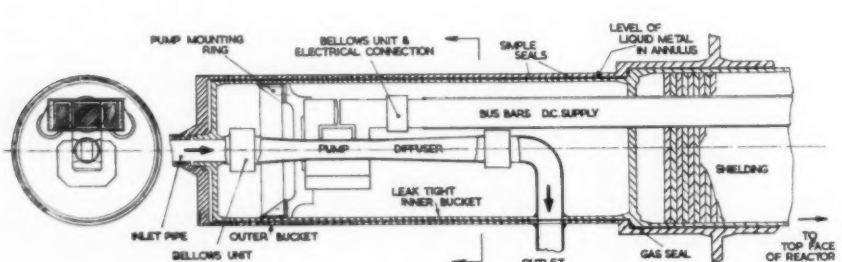


Fig 15 A suggested layout for a d.c. liquid-metal-fuel pump

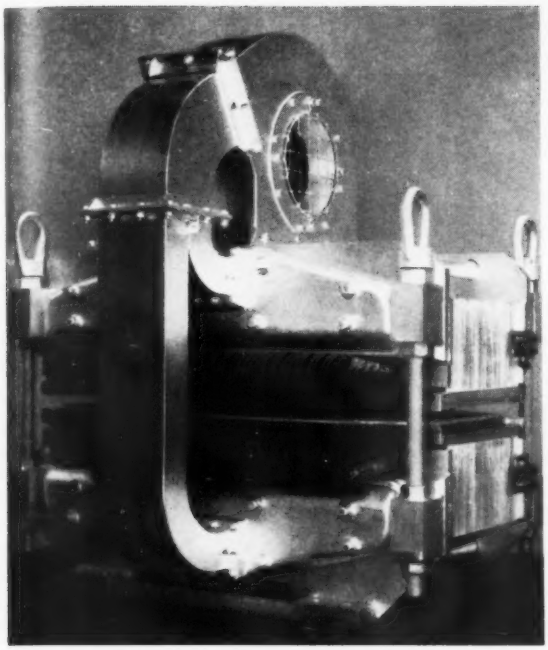


Fig 16 An early prototype of an English Electric FLIP stator (above), duct (below)

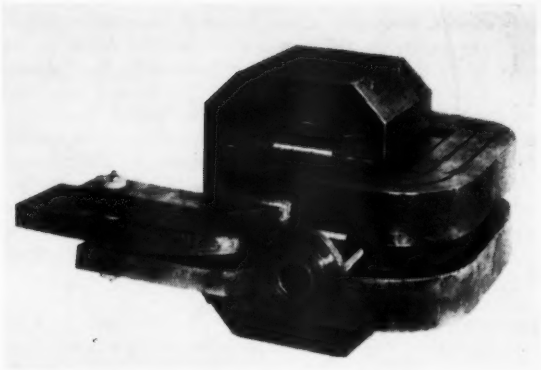


Fig 17 A small d.c. pump by British Thomson-Houston

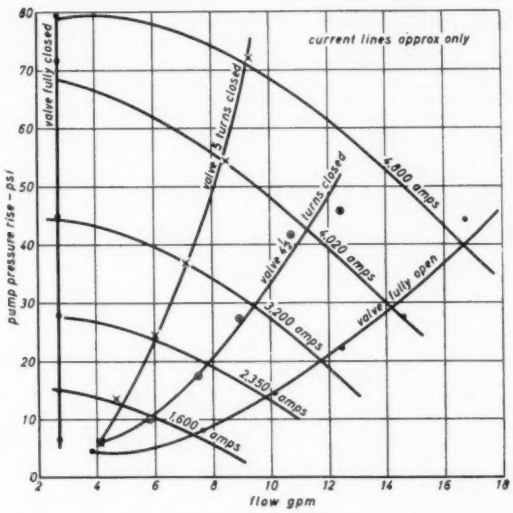


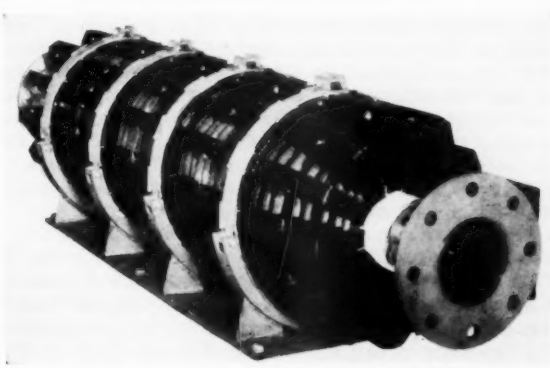
Fig 18 Test results for the BTH d.c. pump of Fig 17

the solution to the problem of operation in intense gamma and neutron fields is to use only ceramics for insulation in the winding, since these are the best materials under conditions of heat and radiation. However, this may be an expensive and difficult technique to develop.

Comparison between e.m. and mechanical pumps

The various types of mechanical pumps which have been proposed for pumping liquid metal are described in another article in this issue. In the early development days there was a marked preference for the e.m. pump for use in the various reactors proposed. Little was known about the standards of leak-tightness necessary and so it was considered wise to develop e.m. pumps in which the liquid metal was contained in a completely welded structure. It was also not known how effective liquid metal would be as the lubricant for submerged bearings and the problems to be encountered with shaft seals were hardly understood. It was natural, therefore, to concentrate development on electromagnetic rather than mechanical pumps. However, an appreciable amount of work has now been carried out on bearings, shaft seals and canned rotor/stator units and it is probably safe to say that liquid metal mechanical pumps could now be made which would have considerable reliability. Generally speaking, mechanical pumps would now be selected rather than e.m. pumps. For instance, EBR1 and EBR2 both employ e.m. pumps, but it should be noted that for the next reactor in the series—the Enrico Fermi Fast Reactor at Detroit—a mechanical pump has been specified. It is not clear however whether this change is due merely to the different layout employed in the reactor or to a new design philosophy. Undoubtedly there will be layouts where e.m. pumps are preferred. It is acknowledged that mechanical pumps have a greater efficiency than e.m. pumps, but in the case of sodium at any rate—where the pumping power is very low—it is doubtful whether this is of any real significance. In the case of the

Fig 19 A BTH annular linear induction pump with cover removed to show construction



heavy metals, however, where pumping powers are larger, there may be an incentive to use mechanical types. In the future when the last fraction of a percentage in efficiency may be necessary and liquid metal technology has been developed considerably, the mechanical pump may completely oust the e.m. type. On the other hand, if the requirement for cleaner liquid metal systems continues, as it appears to be doing at present, the leakproof construction of the e.m. pump might give it the advantage. It is thus extremely difficult at the moment to forecast the future of liquid metal pumping but current development work is expected to have a determining influence.

Reactor e.m. pumps

A considerable number of e.m. pumps have now been operated for long periods in experimental loops up to sizes using six- and eight-inch diameter tubes. Five reactors have been or are being constructed using these pumps and others are proposed. It is known that the American General Electric Co provided e.m. pumps for the land-based prototype and the seagoing version of the Sub-

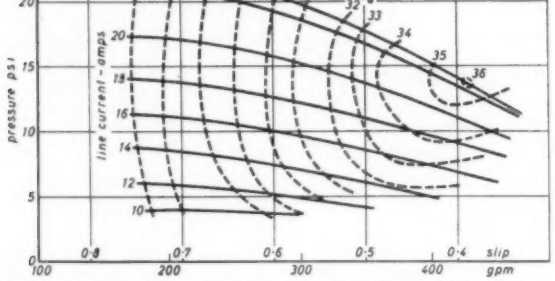


Fig 20 Test results of the ALIP of Fig 19. Pump inlet 7 psi; metal 22/78 NaK at 175°C: winding temp 100°C at max power

marine Intermediate Reactor installed in the *Seawolf*. No details of these are available but it seems probable from published facts that they are of the FLIP type (Fig 23).

In order to illustrate a number of the problems and their solution, of fitting e.m. pumps into reactors, four examples have been chosen for further description.

EBR1

The first fast reactor[23] which produced an appreciable quantity of heat was EBR1, constructed on the National Reactor Testing Site at Arco, Idaho, by the Argonne National Laboratory. The d.c. electromagnetic pump in the primary circuit has a capacity of 500 gpm with a head of 25 psi. The pump is located in a helium atmosphere in a stainless steel enclosure which provides containment for the liquid in case of duct failure and also protection for the copper against oxidation. The busbars are brought into the enclosure through stainless steel bellows which, by introducing a relatively high resistance path, serve as electrical insulators as well as flexible seals. The performance characteristics of this pump are shown in Fig 10. Its efficiency (exclusive of rectifier current supply) at 300 gpm with a head of 40 psi is 43 per cent.

EBR2

In the second fast reactor[24] being built by the Argonne National Laboratory the primary circuit pump is again a d.c. unit (Fig 11) fed from a homopolar generator, whilst the secondary circuit uses a FLIP (Fig 12). Basic to the

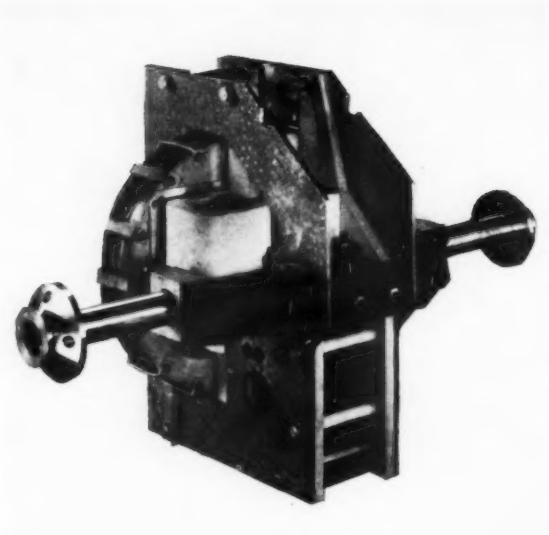


Fig 21 An a.c. conduction pump by Palatine Tool and Engineering Co

EBR2 design is the employment of a primary system—reactor, pumps, piping, heat exchanger, fuel transfer and storage system—completely submerged in sodium in a single vessel. This arrangement probably required the use of a d.c. type of pump and the unit to be used has a capacity of 10,000 gpm (the largest pump so far designed) with a head of 75 psi. The pump duct has a rectangular cross-section of 6in. by 18in., the latter dimension being in the direction of current flow and is constructed from 80-20 nickel chromium sheet 0·065in. thick. The duct is located between magnet poles 42in. long, the sodium velocity in it being 31 ft per second. The current is fed into the duct over a length of 24 inches. The electrical conductor or 'busbar' system consists of stainless steel enclosures

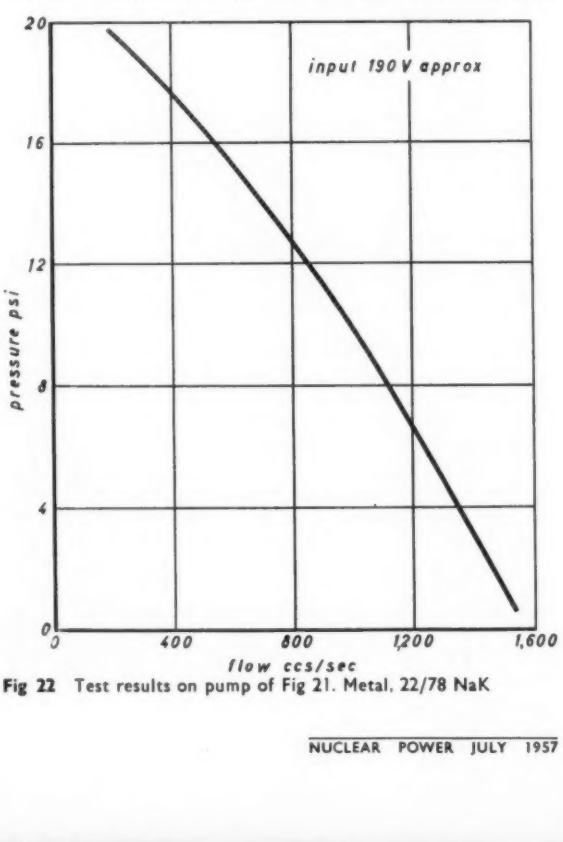


Fig 22 Test results on pump of Fig 21. Metal, 22/78 NaK

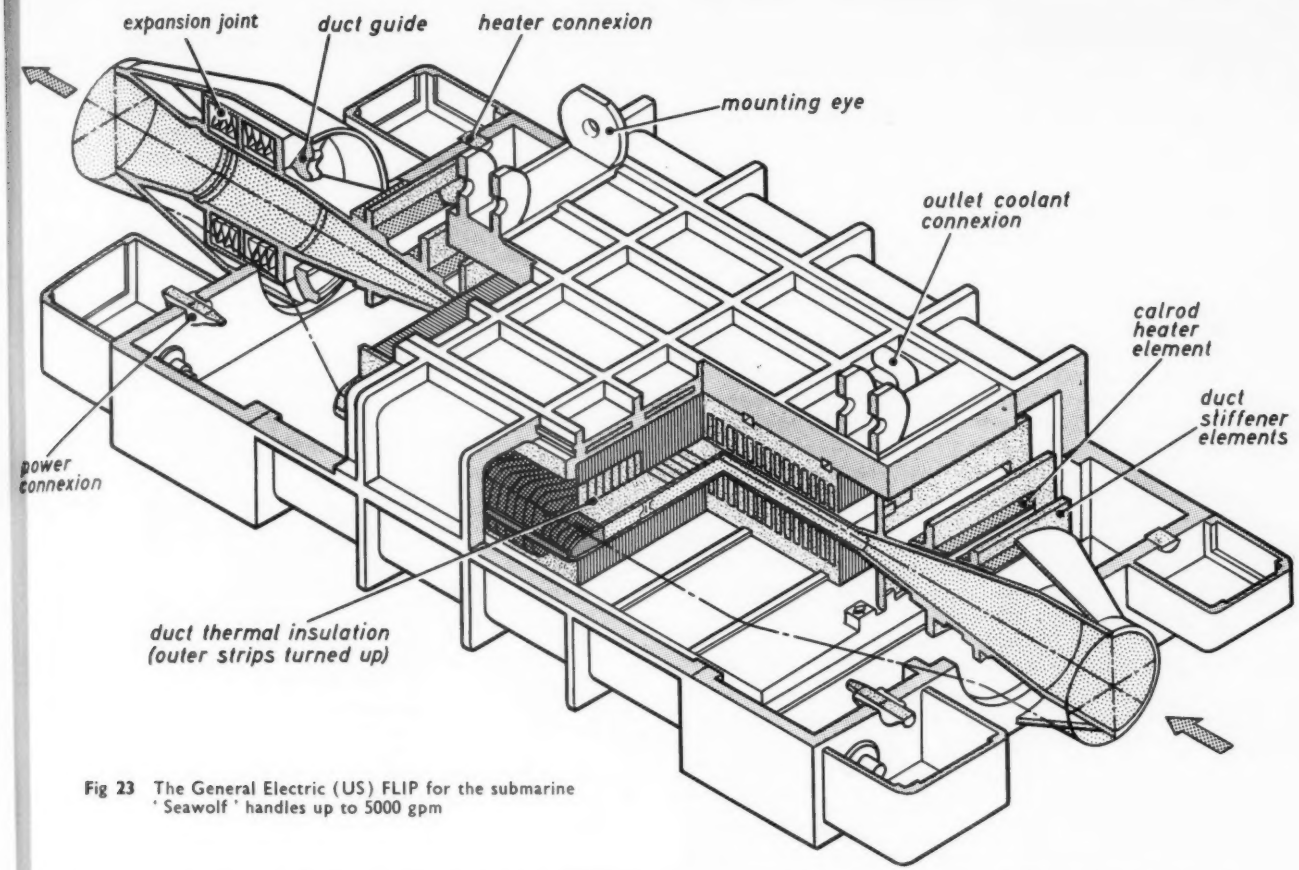


Fig 23 The General Electric (US) FLIP for the submarine 'Seawolf' handles up to 5000 gpm

welded to opposite sides of the pump duct. The enclosures are packed tightly with copper bars and electrical contact with the duct wall is made by a thin layer of liquid sodium. Magnetic field compensation is accomplished by returning the current, which has traversed the liquid, back across the main field through parallel paths on both sides of the duct. The magnet is energized by the main current and, due to its high value of about 250,000 amps, a single turn winding is sufficient. Mica insulation is employed external to the duct and the pole pieces are used to give support against the internal pressure. In order to reduce the fringing current in the liquid ahead of and behind the duct, the latter is divided into ten separate parallel channels each $1\frac{1}{2}$ in. by 6 in. cross section extending for a distance of 6 ft on each side of the magnet. The channels are spaced externally with $\frac{1}{32}$ in.-thick mica insulation. The pump duct and magnet assembly are completely enclosed in a welded stainless steel housing which will be argon filled.

The current of 250,000 amps at 2·5 volts will be supplied by a homopolar generator driven by a 1,250 hp induction motor. The contact with the solid iron rotor will be made by sodium-potassium alloy as a liquid metal brush. The very large current requirement makes it necessary to place the pump and generator as close together as possible. The generator is mounted immediately above the pump external to the shielding and the whole assembly is arranged so that the pump and generator can be removed for servicing.

Dounreay Fast Reactor

FLIP type pumps are being used throughout for sodium circulation in the Dounreay Fast Reactor[25], the primary and secondary coolant circuits of which have been divided into 24 parallel paths each with its own pump. The design of the pumping unit (Figs 13 and 14) was based on the following main assumptions:

a. The pump channel could be made reliable and so would not require maintenance
b. The shape, construction and wall thickness of the channel would be such that only small loads could be applied to it by the main piping
c. The wound cores on either side of the channel might be a source of trouble and so should be designed so that they could be remotely removed for maintenance
d. The channel would not withstand a high internal pressure when the wound cores were removed
e. Containment of the pump in an inert-gas-filled enclosure would be necessary.

Fig 13 shows the design adopted that satisfies these assumptions. The pump unit is contained in a cylindrical container placed on its side. The flat pump channel is placed with its axis horizontal and its longer flat sides in a vertical plane. The magnet cores are therefore held in a vertical position and can be either raised or lowered through shafts forming part of the containment. These shafts allow access to the pumps from above the shield of the reactor. The lifting mechanism for the wound cores is designed so that as they are raised, the cores first withdraw from the channel sides and then lift free from them so that no damage can be done. The channel is suspended from points well up the shaft. The containment around the main piping is connected to the pump cylindrical container by bellows units which allow a seal to be made but cater for thermal movements. Containment is completed by a cover welded to the shaft at the top point above the concrete shield. It will be noted that offset diffusers have been used in the channel construction so that the liquid metal will completely fill and drain from the circuit.

Liquid metal fuelled reactors

Work is being carried out at both AERE, Harwell and Brookhaven National Laboratory, Long Island[12], on a homogeneous type of reactor employing a solution of fissionable material in liquid metal. Owing to the fact that liquid metal fuel becomes highly active, it was decided that it would be advantageous if certain components of the reactor were made removable. Fig 15 shows a method of construction suggested at AERE in which a d.c., e.m. pump is housed in a leak-tight inner 'bucket,' through the top of which are brought the necessary d.c. supplies. This inner bucket is situated in an outer bucket of similar shape to which are connected the inlet and outlet pipes of the coolant circuit. A simple seal is placed between the two buckets in order that the leakage between the outlet and inlet of the pump is kept to a minimum. The two buckets are carried up to the top of the biological shield and a completely leak-tight seal made between them. If and when a pump requires maintenance, the reactor is allowed to cool, the seal broken and the pump within its bucket is raised into a leak-tight coffin. The inner bucket normally contains an inert gas and relative expansions are catered for by suitable bellows. The level of the liquid metal in the space between the two buckets must be kept at a predetermined level and emergency overflow and high liquid metal detection arranged.

Manufacturers

America and Britain have so far been responsible for most development work on e.m. pumps. Most of that in the UK has been either under contract to or encouraged by the Atomic Energy Authority. The very first work in this country was done by Murgatroyd and Trefethen at Cambridge during 1947 whilst trying to devise pumps for the circulation of mercury in heat transfer rigs.

Four companies are manufacturing pumps in the UK:

a. The English Electric Co Ltd
b. The British Thomson-Houston Co Ltd
c. Palatine Tool & Engineering Co
d. Campbell and Isherwood Co Ltd

Fig 16 shows a photograph of the prototype FLIP manufactured by the English Electric Co for the Dounreay Fast Reactor.

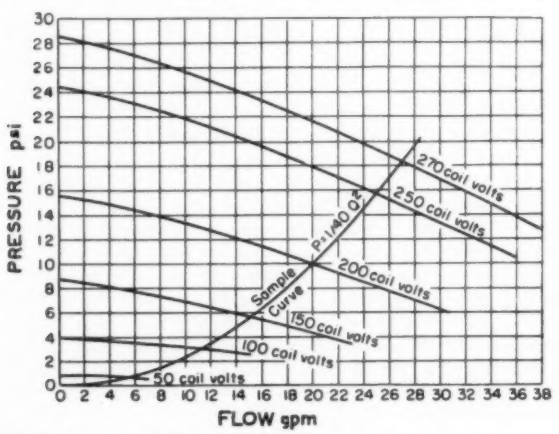


Fig 24 Characteristics of a small a.c. conduction pump by GE (US)

Photographs of a small d.c. pump and an ALIP manufactured by the BTH Co together with their characteristics are shown in Figures 17-20.

An illustration of a small a.c. conduction pump manufactured by the Palatine Tool & Engineering Co. is shown in Fig 21 with its performance in Fig 22.

In the USA the three main laboratories concerned with e.m. pump development are the Argonne National Laboratory, the Knolls Atomic Power Laboratory and the Oak Ridge National Laboratory. Many firms have collaborated with these laboratories, the principal ones being Allis Chalmers Manufacturing Co, General Electric Co, Babcock & Wilcox Co, Mines Safety Appliances, and Callery Chemical Co.

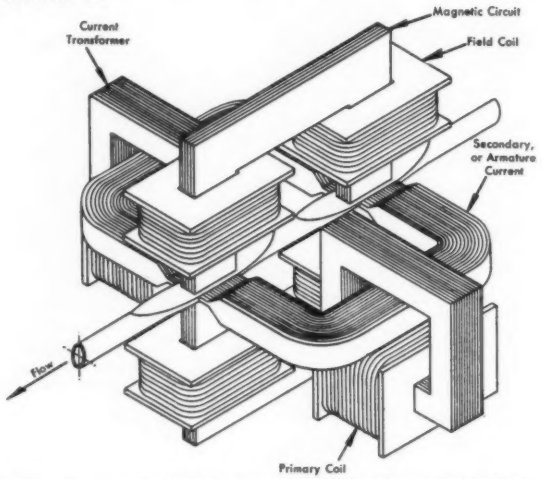


Fig 25 The a.c. conduction pump by Callery Chemical Co (US) incorporates two flattened portions in the duct

Due acknowledgment is given to the various authors, firms, authorities, and publishers from whose papers most of the information contained in this review has been abstracted. Many of the principles of the various pumps are covered by patents in the USA and the UK.

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Nuclear Power Special Pump Issue

MECHANICAL PUMPS AND CIRCULATORS

A survey by F. L. SPEED, AMIMechE,

Atomic Energy Research Establishment, Harwell

NUCLEAR REACTORS and their associated process plants demand mechanical pumps with a standard of containment very much in excess of that previously demanded by industry. No power reactor can operate without pumps, and while great progress has been made in this country during the last few years to develop pumps to meet the requirements of the British type of gas-cooled, graphite-moderated reactor, it is a fact that the lack of efficient, utterly reliable pumps is one of the factors at present limiting the development of certain advanced types of reactor such as the homogeneous aqueous and the liquid-metal-fuelled varieties. The object of this article is to review the various types of mechanical pumps that have been used for handling coolants and liquid fuels. A brief reference to gas circulators is also included because of their importance in the UK power programme.[1]

A great many reactor types are possible and this produces widely varied requirements for coolant pumping. Pumps are required for operating at various pressures and temperatures with (a) gases (b) aqueous fluids and aqueous slurries (c) organic fluids and (d) liquid metals

Mechanical pumps of the positive displacement type, including the fluid-actuated diaphragm type, are excluded from this review because, although well suited for auxiliary processes in reactor systems, they are not considered as suitable for main coolant circuits on account of their low flow rates, pulsating pressures and susceptibility to diaphragm failure under prolonged continuous service. Pumps with sliding mechanical parts are not very suitable for many applications, because of the impossibility of providing boundary lubrication in the presence of the pumped fluids.

Attention is therefore concentrated on the centrifugal type of pump, because it is basically a rugged machine with high reliability due to its simplicity of construction. It appears to be ideally suited for the conditions of pumping in a reactor because for a given capacity it offers the following advantages:

1. small size
2. good efficiency
3. low cost
4. readily adapted to a high speed electric motor or turbine drive
5. possesses a minimum of moving parts and bearing surfaces

The hydraulic characteristics for reactor circulating pumps do not in themselves present very much difficulty, as pumps have already been developed for industry to meet similar requirements. The main problem for the pump designer is the demand in most cases for zero leakage from the pump casing and gland and the limited selection of suitable materials.

Centrifugal pump units may be divided into two main classes. (1) Controlled Leakage and (2) Hermetically Sealed. These are distinguished mainly by the method used to provide a mechanical drive to the impeller.

1. Controlled Leakage

The majority of pumps used in industry are based on this principle, which relies on a packed stuffing box, or a mechanical seal to prevent excessive leakage of the pumped fluid where the driving shaft passes through the pump casing. Both the bearings supporting the impeller and the driving motor are outside the pump casing. With the conventional arrangement the shaft seal is in direct contact with the pumped fluid and a controlled outward leakage of this fluid, or alternatively, a controlled in-leakage of another acceptable fluid must be tolerated. This is necessary because most packed seals depend on the use of an elastic material which has to be compressed into close contact with the pump shaft and casing or, in the case of the mechanical seal, pressure on two optically flat mating seal faces is essential. Both these arrangements rely on some form of cooling to remove the friction heat generated at the seal when the pump shaft is rotating. The packed gland usually works on the controlled leakage principle to alleviate this heating and also provides lubrication in the packing—particularly when used for high pressures. It is necessary to circulate sufficient cooling fluid past the mating seal members of the mechanical seal to avoid distortion of the optically flat faces by local overheating. Very low leakage rates are possible with this type of seal.

There are of course many variations of design on the general principles of this method of sealing a rotating shaft and it is of interest to describe several of these in some detail.

(a) High Pressure Shaft Seals

There are many high pressure circulating pumps operating at 1500—2000 psi suction pressure and 600°F (315°C) water on La Mont boilers. Except where the glandless type is used, most of these pumps are fitted with one of two types of shaft seal—(a) breakdown bushing and (b) floating rings. Both are used in conjunction with a packed seal in a stuffing box.

Fig 1 illustrates at A the arrangement used for breakdown bushing and at B the floating rings seal. In each

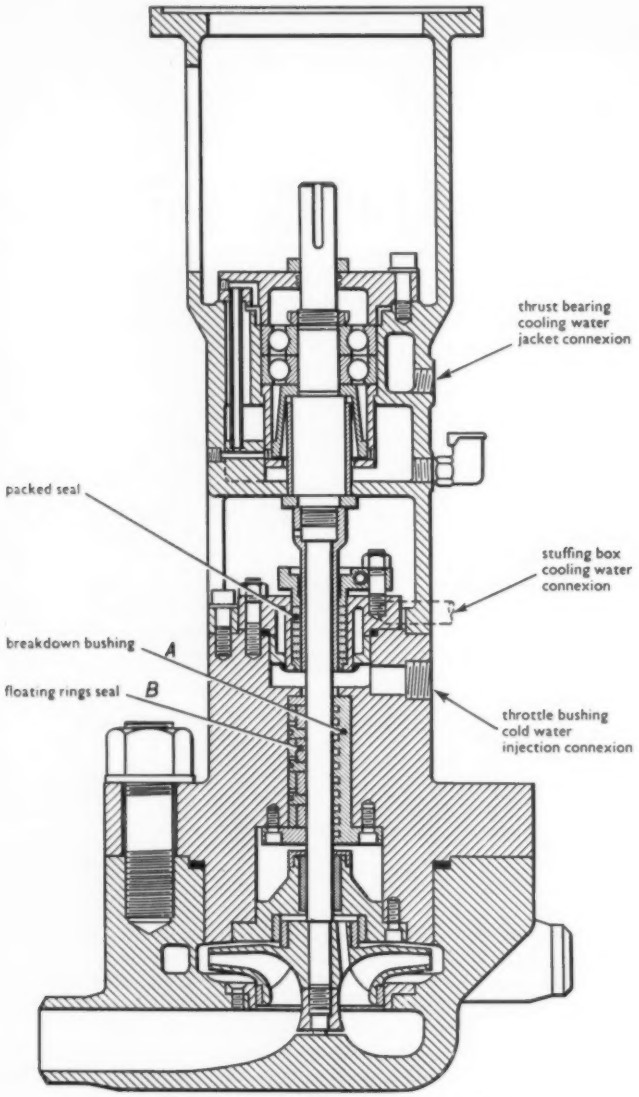


Fig 1 A high pressure boiler circulating pump with (a) Breakdown bushing; (b) Floating rings seal

case the object is to provide a restriction which reduces the pressure of the liquid coming in contact with the packed seal so as to control the amount of liquid which is allowed to leak out of the packing.

It is essential to ensure that the liquid leaking through the packing is cooled and this is usually done by feeding cold water to the space between the breakdown bushing or floating ring seal and the gland packing, so that it mixes with hot water leaking through the restriction from the pump end. In addition low pressure cooling water is supplied to a jacket constructed round the stuffing box.

This design may be considered for use with reactor coolants of low activity, provided the leakage from the packed seal is collected efficiently and either returned to the reactor system or drained away to the effluent disposal plant. It is of interest to note that the first Russian pressurized water power reactor operated with this type of pump.

Some development work has been undertaken in the USA to try and reduce leakage by using a mechanical seal in place of the breakdown bushing or floating ring. So far as is known only the smaller sizes have been tried in service and very low leakage rates have been reported, although no data on reliability is available. Fig 2 illustrates a typical double mechanical seal arrangement for a boiler circulating pump. The application of mechanical seals to very high pressure is admittedly difficult, but with development, aimed particularly at more efficient cooling of the seal faces, it may be possible to devise mechanical seals which will be reliable on large size medium pressure pumps.

Approximate leakage rates for a boiler circulating pump having a 4in. dia. shaft and operating at 2000 psi suction pressure are quoted as:

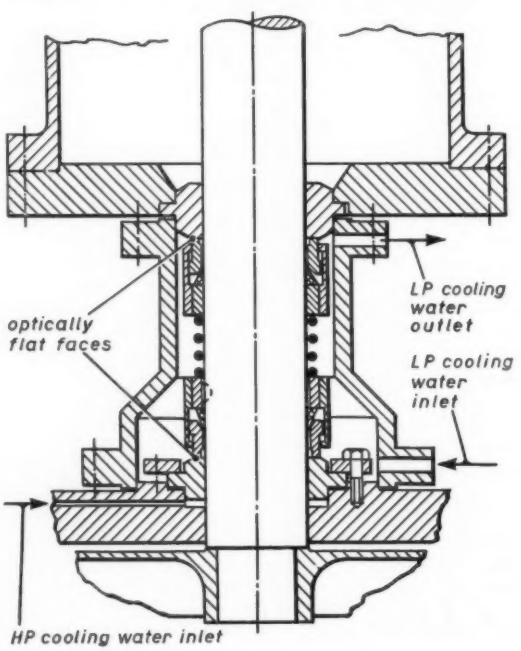
a.	Breakdown bushing	2000 gallons/hour
b.	Floating Rings Seal	1000 gallons/hour
c.	Mechanical Seal	5 gallons/hour

(b) Frozen Seal Pump

The pumping of liquid metals at high temperature is attractive for a number of reactor proposals, but has presented several unique sealing problems. The difficulties lie in the rapid deterioration of ordinary seal and packing materials, by the chemical action and high temperature solidification characteristics of liquid metals.[3,4,5] A considerable amount of work has been carried out on the development of electromagnetic pumps[6] as a solution to the shaft seal problem, but the efficiency of these is comparatively low and the cost of development and manufacture is high, so for large power proposals an alternative shaft seal has been investigated[2] involving principles where the freezing property of the liquid metal is used to advantage.

Sealing is achieved by forming a frozen annular plug of the pumped metal in the narrow clearance where the pump driving shaft passes through the casing. When the pump is operating the frozen metal is continuously sheared

Fig 2 A mechanical shaft seal for a boiler circulating pump



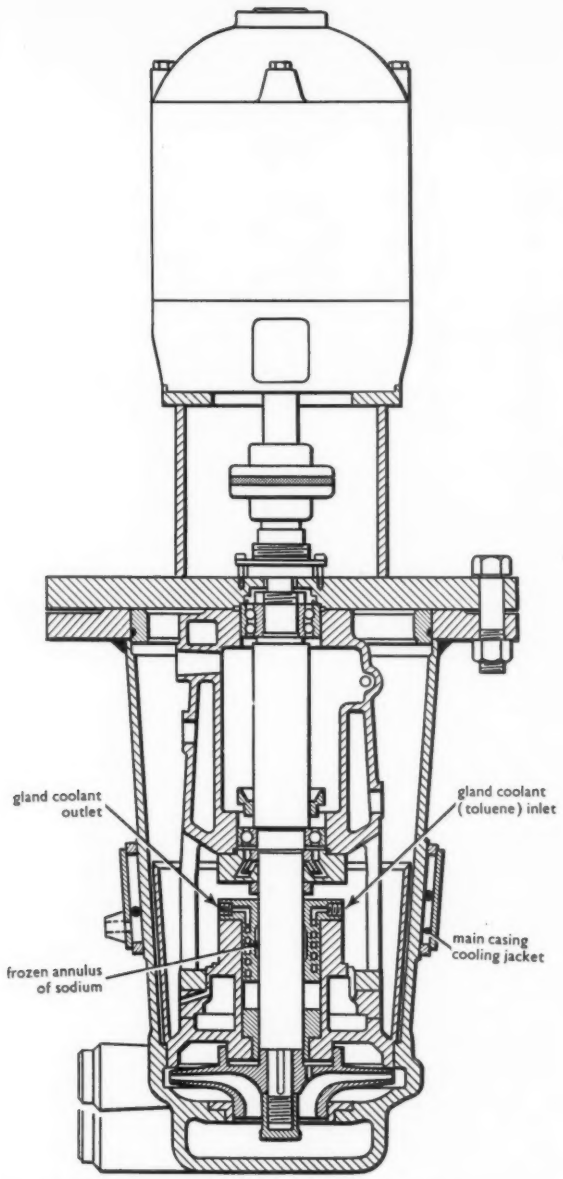


Fig 3 An American frozen seal pump for liquid sodium

at the shaft surface and a thin high viscosity liquid film is maintained at the shear interface. It is thought that friction energy supplies the small amount of heat necessary to maintain the liquid film and the high conductivity of the liquid metal allows rapid heat removal, so that the film does not become thick enough to allow leakage. This heat and also the heat conducted from the pump end is continuously removed with a secondary coolant fluid.

Liquid metals such as sodium oxidize very rapidly in contact with the atmosphere, so it is necessary to provide an inert gas blanket adjacent to the outside of the frozen seal to prevent the formation of abrasive oxides in the seal which can lead to binding and seizure of the pump shaft.

Fig 3 shows an arrangement of an American frozen seal pump for use with sodium. Experience has shown it is better to arrange the pump vertically because with the horizontal arrangement difficulties are encountered in obtaining a seal plug free from pockets and this can lead to in-leakage of the blanket gas.

Frozen seals for sodium pumps appear to be very promising, but they have not yet been developed to a satisfactory stage of reliability. A major problem is the provision of a secondary cooling system which is not subject to failure. Frozen seals are only able to withstand pressures across the seal of the order of a few pounds per square inch.

(c) Gas Circulators

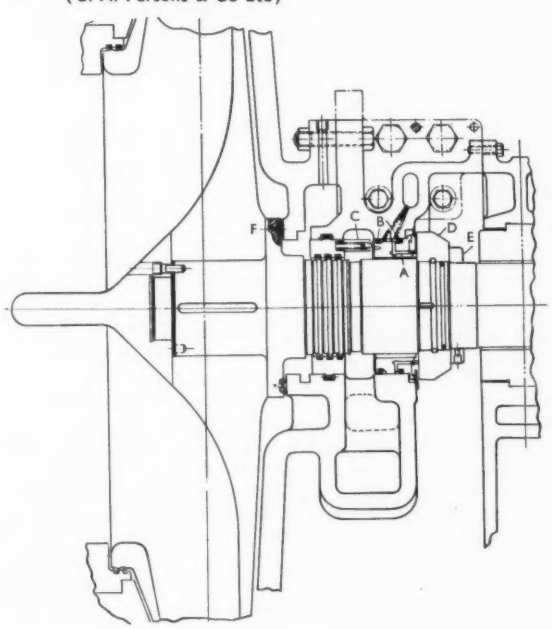
The shaft seal for the Calder Hall main gas circulators are also designed on the controlled leakage principle. These are required to seal against CO_2 at 100 psig and 284°F (140°C).

The detail design of the seal is shown in Fig 4 and is similar in construction to the mechanical seal. Seals of this type have previously been used for lower pressures on hydrogen-cooled alternators.[8]

The floating ring A is fitted with two sealing rings B and is located on a spherical seating. It is spring loaded C against a loose collar D keyed to the shaft and held by the nut E. An 'O' ring seals the gap between the loose collar and shaft. The collar D has a nitrided face, whereas the floating seal ring A, which is $\frac{1}{8}$in. eccentric to the axis of the shaft, is faced with white metal.

Oil at a mean pressure of 105 psi (5 psi above the CO_2 pressure) is fed to the space between the seals on the floating ring A. From here the oil flows through the passages radially and then axially to an annulus on the sealing face. Radial grooves leading outwards from this annulus allow the passage of about 99·9 per cent of the seal cooling oil to an atmospheric drain, whilst a smooth plane face inwards from the annular groove and bearing on the nitrided collar forms the seal. The large outward flow of oil in conjunction with the gas pressure and spring loading on the floating ring A controls the gap at the sealing face. The small amount of oil passing inwards across the seal face drains to a pressurized detraining tank, from which it escapes by a float operated valve to an atmo-

Fig 4 Shaft seal on the Calder Hall gas blower (C. A. Parsons & Co Ltd)



spheric degasifying tank, thus liberating the entrained CO_2. This is then vented to atmosphere and the oil is passed back to the main oil tank.

Under full pressure and temperature operating conditions the quantity of seal oil flowing to the detraining tank is approx. 1 gph. The loss of CO_2 absorbed by the oil and released to atmosphere under these conditions is about 5lb/day.

A labyrinth type gland is fitted on the shaft between the oil seal and the circulator casing to prevent excessive leakage of oil into the circulator in the event of seal failure and to deter the back diffusion of oil vapour into the circulator.

It is to be expected that as a direct result of the UK power programme we shall see considerable development and alternative proposals for sealing gas circulators at higher operating conditions than those in the Calder Hall reactor.

(d) Overhung Shaft Seal Bowl Pump

Fig 5 shows another pump arrangement which avoids having the shaft seal in contact with the pumped fluid and this method is particularly useful when the pumped fluid cannot be used to cool or lubricate the packing or seal faces e.g. liquid metals, fused salts or slurries.

The pump is vertically overhung from conventional lubricated bearings and operates in a tank of the pumped liquid which is arranged with a gas/liquid interface. This tank is usually designed to act as the expansion tank of the system. This arrangement transfers the problem of sealing from the liquid to the gas phase. In the case of liquid metals such as sodium an inert gas blanket has to be used and to avoid oxidization of the liquid metal, low leakage of this gas is essential. This is because any make up of gas, even after purification, contains small percentages of impurities which, on an accumulative basis, can be embarrassing in a closed circulating system.

The pump illustrated was designed for use with sodium in a laboratory high temperature heat transfer rig. The gas seal was specially developed to seal against 7—10 psig and a leakage rate of approx. 0·4 cc/hr at n.t.p. was obtained when the pump operated at 3000 rpm.

The seal unit is comprised of two lip-type synthetic rubber oil seals which operate on a sleeve clamped to the rotating shaft. To remove the frictional heat from the two seals an auxiliary cooling circuit is provided in which oil is circulated between the two seals and the heat rejected to an oil/water cooler. The sleeve is arranged so that the cooling oil is circulated directly beneath the point where the seal friction is generated. The use of the sleeve construction also provides a convenient reservoir where any leakage of oil past the lower seal is collected and returned via two large drain lines to the cooling oil sump tank. An additional labyrinth gland is incorporated to ensure that oil from the reservoir does not leak into the liquid metal bowl. The oil system is maintained at the same pressure as the blanket gas by the two large drain lines which also act as balance pipes between the gas space above the liquid metal and the space over the cooling oil in the sump tank. This allows the lower seal to operate with no pressure difference across it and therefore friction forces are confined only to the normal garter spring loading.

The main disadvantage of this type of pump is the limitation imposed on the siting of the pump in the system due to the need for a gas liquid interface and level control. Care has also to be taken in the design to avoid turbulent liquid conditions occurring in the pump bowl, because of the danger of entraining blanket gas in the liquid. This difficulty can easily be overcome by suitable baffling to ensure that liquid velocities are kept low.

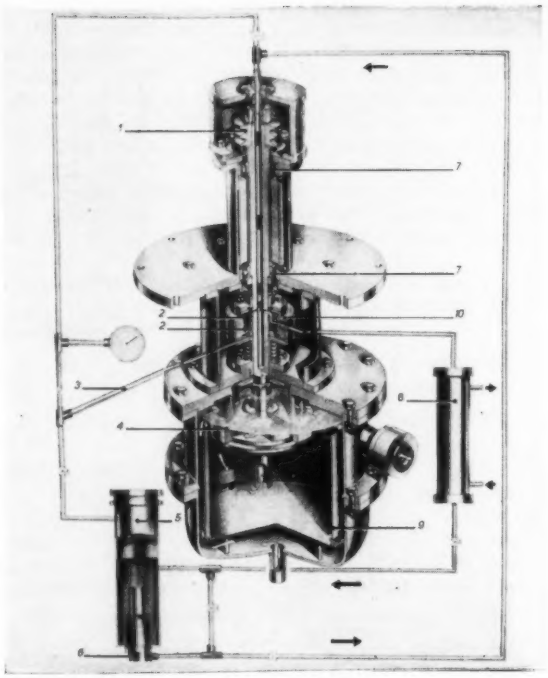
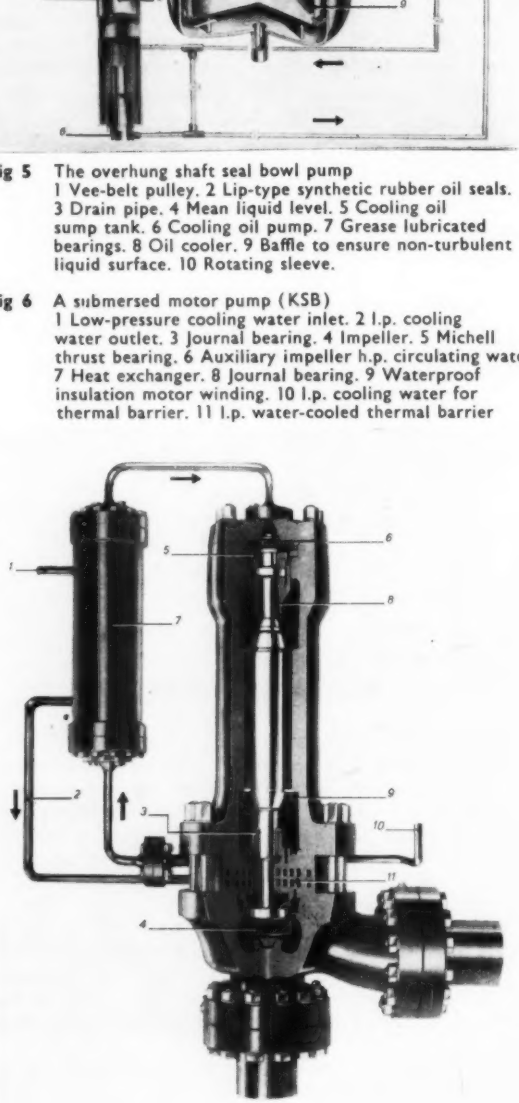


Fig 5 The overhung shaft seal bowl pump
1 Vee-belt pulley. 2 Lip-type synthetic rubber oil seals. 3 Drain pipe. 4 Mean liquid level. 5 Cooling oil sump tank. 6 Cooling oil pump. 7 Grease lubricated bearings. 8 Oil cooler. 9 Baffle to ensure non-turbulent liquid surface. 10 Rotating sleeve.

Fig 6 A submersed motor pump (KSB)
1 Low-pressure cooling water inlet. 2 l.p. cooling water outlet. 3 Journal bearing. 4 Impeller. 5 Michell thrust bearing. 6 Auxiliary impeller h.p. circulating water. 7 Heat exchanger. 8 Journal bearing. 9 Waterproof insulation motor winding. 10 l.p. cooling water for thermal barrier. 11 l.p. water-cooled thermal barrier



2. Hermetically Sealed

There is no doubt that for service in nuclear plant and the chemical industry where leaktight pumps are essential the 'Hermetically Sealed' pump unit is the most promising approach to the problem. These pumps are built in the following variations of design:

a. Submersed Motor
b. Canned Motor
c. Magnetic Coupling
d. Gas Bearing Motors.

(a) Submersed Motor

Submersed motor pumps[9] were first used in borehole pumping applications and subsequently developed into the type illustrated in Fig 6 for use as high-pressure boiler circulating pumps. In this unit the pumped fluid is also allowed into the motor compartment to submerse the rotor, bearings, stator laminations and windings. The motor casing has therefore to be designed to withstand the full pressure of the pumped fluid. Because of its simplicity of construction and minimum number of parts the squirrel-cage induction motor is used as the driving unit.

The stator windings are covered with watertight insulation made from p.v.c. or polythene reinforced with a thin nylon skin. Polythene is preferable in pumps which are used with fluids containing small amounts of radioactivity because of its better resistance to radiation. However, polythene has a sharp melting point of about 212°F (100°C), so it is necessary to provide a reliable cooling system to maintain the motor at about 130°F (55°C) and adequate instrumentation is essential to guard against overheating in the motor windings. High pressure water-tight insulated seals are used to pass the electrical connexions through the motor casing.

The bearings are lubricated by the liquid in the motor compartment and the heat which is generated in the bearings and the motor, also the heat leaking from the hot liquid in the pump end, is carried away by a small quantity of liquid circulating in a closed system between the motor and an external cooler. The circulation is caused by an impeller fitted to the top end of the motorshaft. In some designs this is incorporated in the thrust disc. A water-cooled heat barrier is fitted between the pump and the motor to reduce the amount of heat which has to be removed in the motor cooling circuit. A labyrinth seal is incorporated in this heat barrier to restrict the interchange of liquid between the pump and motor compartments.

Plain journal bearings are usually used and good results have been obtained with stellited or hard chromed shafts operating in bushes of plastic or graphite compositions. Similar materials are also used for the thrust bearing which is a Michell type to ensure full film lubrication and maximum load carrying capacity. One manufacturer in the UK also uses Michell type of journal bearings, comprised of a ring of stainless steel pads running against a sleeve of plastic material.

Pumps of this type (Fig 7) are used to circulate heavy and light water coolants at temperatures up to 175°F (80°C) on research reactors. Small units have also operated on an in-pile loop experiment with water at high temperature and pressure, but as far as is known the submersed motor pump has not been used for circulating the main coolant of a high temperature power reactor. The most likely reasons for this appear to be:

a. the possibility of cooling water failure and likely overheating of the motor windings, leading to subsequent pump failure

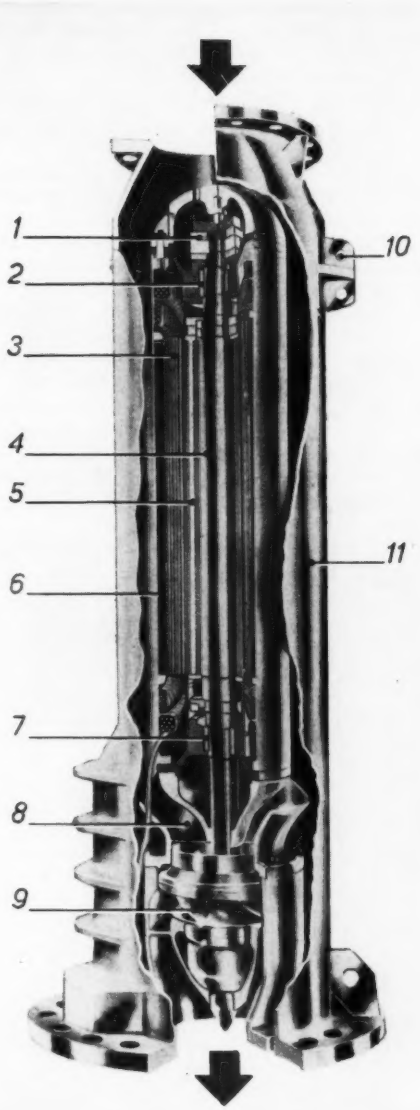


Fig 7 Submersed motor heavy water pump for DIDO reactor (Hayward Tyler)
1 Thrust bearing. 2 Journal bearing. 3 Waterproof windings. 4 Rotor shaft. 5 Rotor bars. 6 Stator. 7 Journal bearing. 8 Pump suction. 9 Impeller. 10 Lifting lugs. 11 Stainless steel shell

b. the problems associated with a ruptured fuel element causing activity in the pumped fluid and the inevitable difficulty of thoroughly decontaminating the motor, because of the many crevices in the windings and stator stampings where active particles can lodge.

It seems that further development on the submersed motor could be aimed at reliable operating with high temperature resistant insulations which are also compatible with the pumped fluid. An attractive proposal for some applications is the possibility of avoiding the use of a cooling system altogether and allowing the motor to operate at the same temperature as the pump. This proposal would, of course, reflect on the problems of bearing design, because of the reduced viscosity of fluids at the higher tem-

peratures, but for some applications this need not present an insuperable problem.

(b) Canned Motor

The canned motor pump[10,17] was developed from the submersed motor pump with the object of overcoming some of the disadvantages of the wet motor.

This is achieved, as shown in Fig 8, by inserting a thin (usually about ·020in. thick) metallic can or sheath of non-magnetic material in the gap between the motor and stator and seal welding this to the end plates of the stator compartment to form a housing which encloses the stator laminations and windings. Support for the thin can against system pressure is provided by the stator laminations and by thick backing sleeves in the compartments which accommodate the winding end turns. For high temperature applications the motor windings are made to Class H specifications which permits the use of temperatures up to 356°F (180°C) in the motor. Some difficulty can be experienced, particularly with the larger sizes, in removing the heat generated in the end turns of the motor windings. This is usually overcome by using thicker copper wire

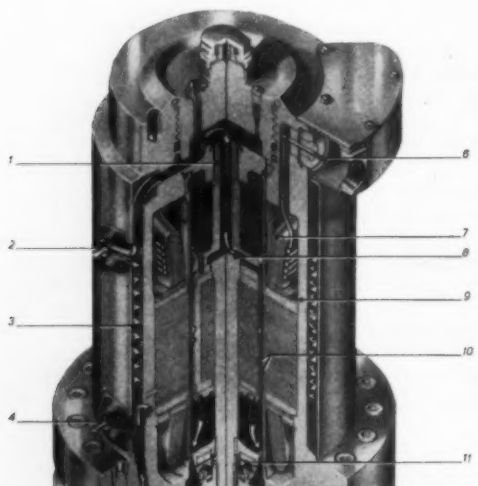


Fig 8 Canned motor pump (Westinghouse)
1 Self-aligning journal bearings. 2 l.p. cooling water inlet. 3 Wrap-around h.p. tube heat exchanger. 4 l.p. cooling water outlet. 5 Heat barrier and labyrinth seal. 6 Motor terminals. 7 Class H insulated motor winding. 8 Auxiliary impeller circulating h.p. cooling water. 9 h.p. motor casing. 10 Non-magnetic stator and rotor cans. 11 Michell thrust bearing. 12 Self-aligning journal bearing

cross sections at the end turns and fitting copper fins between the ground insulation of every coil layer at the end turns and the motor frame. Some pumps are made with oil-cooled windings, but these are usually not very satisfactory for atomic energy applications because of the risk of oil contamination in the circuit, in the event of a can failure. Protection is provided in the event of a pump can failure by designing the motor casing and the insulated motor terminal seals to withstand the full working pressure of the pump. The cooling system is similar to that used on the submersed motor pump. The illustration shows how several manufacturers build the high pressure cooler round the pump body and this makes for a very compact installation.

Hydrodynamic self-aligning sleeve bearings in materials similar to those in the submersed motor pump are normally used although for some fluids it is necessary to have bearings made of very hard materials such as tungsten carbide, stellite and ceramics because they are more resistant to scuffing during the most severe loading conditions of starting and stopping.[11, 12] One manufacturer in the US uses the hydrostatic or pressure fed pocket bearing in conjunction with all metal materials. A particularly difficult bearing problem is presented when the canned motor pump is used to circulate aqueous slurries because it is essential to keep all solid particles away from the rotor and bearing compartment. One method which has been tried to overcome this difficulty depends on the supply of an additional fluid free from solids being flushed continuously through the motor compartment into the pump end of the unit. Although some progress has been made along these lines it seems that much more development will be required before the canned motor can be classed as a reliable unit for slurry pumping.

Because of the can and the necessity of having a larger magnetic gap the efficiency of the canned motor is less than that of the submersed motor. Large canned pump units up to 1250 h.p. delivering water at 17,000 gpm, 650°F (343°C) and 2,500 psi suction pressure have been built in the US for reactor systems. An increasing number of medium and low pressure units are also being used in the chemical industry where product leakage is important.[13,14]

As with the submersed motor, development of the canned motor pump will be aimed at operating the motor at higher temperatures with a view to overcoming potential failures of a secondary cooling system.

(c) Magnetic Coupling

The combination of a pump and a magnetic coupling in a single unit is a useful way of obtaining an hermetically sealed unit, mainly where non-standard or variable speed drives are required. Although electrically energized magnetic couplings have been designed for this purpose the permanent magnet type is described because it is more compact and does not rely on auxiliary equipment, which can be a source of unreliability.

Fig 9 shows a typical pump arrangement where the magnetic coupling consists of two rings of horse-shoe permanent magnets, positioned so that their poles face each other and are separated by a small gap. The magnets are mounted on two discs, one of which is mounted on the driving shaft and the other on the driven pump shaft. Those on the driven side are totally enclosed in a non-magnetic housing to protect them from the fluid being pumped.

A thin metal can or sleeve is fitted in the gap between the magnet poles and bolted to the pump casing to seal the unit. As the outer ring of magnets attached to the driving shaft is rotated, it pulls the inner ring attached to the pump shaft with it.

The pump bearings are hydrodynamic sleeve type operating in the pumped fluid, with materials selected according to the corrosion and temperature requirements. The driving shaft is mounted on ball bearings located in a housing attached to and outside the main pump casing.

Couplings of this type are manufactured in this country to transmit up to 20 hp at 1,500 rpm. It is difficult to design units for much higher powers, except at proportion-

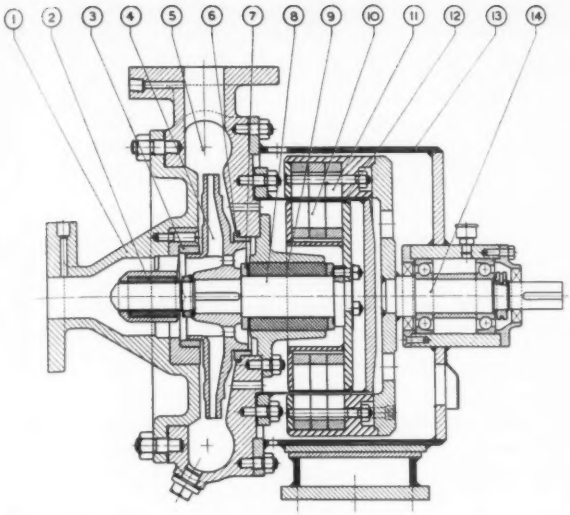


Fig 9 A permanent magnet coupling pump
(Hydraulic & Mechanical Developments Ltd)
1 Front cover. 2 Front bearing. 3 Front neck ring.
4 Impeller. 5 Casing. 6 Back neck ring. 7 Thrust collar.
8 Impeller shaft. 9 Back bearing. 10 Driven magnet ring.
11 Driving magnet ring. 12 Sealed shroud.
13 Coupling housing. 14 Driving shaft

ally higher speeds, which are within reasonable centrifugal stress limits for the large diameter rings required to accommodate a sufficient number of magnets. Operation at pressure is also limited by the thickness of sealing can and magnetic gap which can be tolerated, consistent with the power requirements. Reasonably high temperature operation is possible, provided care is taken with the materials selected and bearing design.

(d) Gas Bearing Motor

Gas bearings[15,16] are usually used where contamination of the process fluid by oil or grease lubrication is considered to be embarrassing. Their ability to operate in gases over a wide range of pressures and temperatures and the resistance of gases to radiation decomposition makes them particularly attractive for a number of atomic energy applications.

As with liquid lubricated bearings there are two basic types of gas bearing, hydrostatic and hydrodynamic. The hydrostatic or pressure-fed bearings permit for the same loading conditions smaller bearing sizes to be used than the hydrodynamic or self-acting type. However for certain applications where no source of pressure gas can be made available or the exhaust cannot be disposed of, the self-acting bearing, within its loading characteristics, provides a very simple arrangement. Except in cases where high static loads have to be carried and jacking by pressure fed gas is necessary during starting and stopping, the absence of auxiliary pressurizing equipment also contributes towards simplicity: hence the reliability of the self-acting bearings. For obvious reasons the static loading of the gas bearing is lower than the corresponding size of oil bearing. With self-acting bearings this is usually arranged to be not more than 2-3 psi of projected bearing area.

Encouraging results have been obtained with a limited number of tests carried out at Harwell on a machine fitted with a shaft weighing 300lb. The bearings are 7in. dia. and 14in. long and the machine can coast to rest from 3,000 rpm without jacking air and with negligible scuffing of the bearing surfaces.

Fig 10 shows a typical application of gas bearings to a gas circulator which was designed at Harwell. This is used to circulate oil-free carbon dioxide at a mean pressure of 100 psig and about 300°F (149°C) through an experimental in-pile circuit.

The impeller is carried at one end of a hollow shaft which runs in two self-aligning, self-acting gas bearings and the squirrel cage induction motor is located between the two bearings. At the other end of the shaft, thrust is taken on a self-pumping type of thrust bearing, which is comprised of a self-aligning fixed plate and rotating plate each with lapped optically flat faces. One plate has a number of shallow spiral grooves cut in its face and when the circulator is running the pumping action of these provides a film of gas between the two plates to carry the thrust loading.

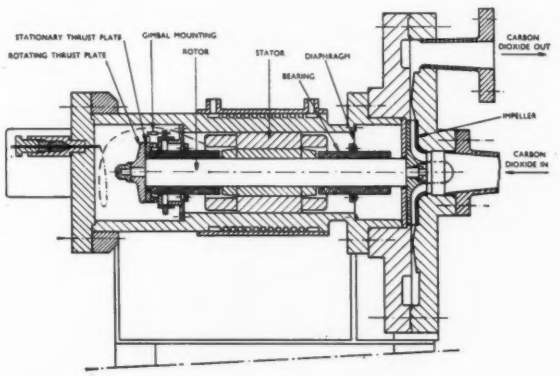


Fig 10 An experimental carbon dioxide circulator driven by a gas-bearing motor

The development of gas bearings has in the past been aimed particularly at gas circulating machinery but the pump illustrated in Fig 11 was designed at Harwell for use with liquid metals and organic fluids. It is a later conception of the bowl type pump in Fig 5 and the object of this design was to overcome the problems of wear, leakage and reliability associated with the blanket gas seal and its auxiliary equipment.

In this case the complete motor is located vertically inside the pump casing similar to the submersed motor unit, except that, instead of the motor running in the pumped fluid it operates in the blanket gas, which is usually argon or nitrogen.

The journal bearings consist of a chromium plated steel shaft running in cast iron meehanite bushes, and the stationary thrust plate is of carbon-copper composition to reduce starting torque and to provide good anti-galling properties for starting and stopping.

Heat conducted up the outside casing and also heat losses from the motor are removed in the low pressure water cooling jacket around the motor casing.

Several pumps of this design are operating very successfully in experimental circuits at Harwell and there is no doubt that gas bearing motor units designed within the recognized bearing limitations and made from correctly chosen materials are reliable and will give long life: they can be started and stopped tens of thousands of times with insignificant wear.

For applications where liquid fuels or slurries are circulated in a reactor, strong radiation fields are likely to be present in the liquid in the pump bowl and it is then

necessary to provide suitable nuclear shielding to protect the motor windings.

The gas bearing motor liquid pump has to be located, in common with the overhung shaft seal bowl pump, at the highest part of the system to provide the gas liquid interface and level control. This limitation can be a disadvantage in some circuits.

Although it is reasonable, during normal operation, to balance part of the weight of the rotating parts by the end thrust design of the single sided impeller, the size of unit which can be made to the design illustrated in Fig 11 is limited by the static loading capacity of the viscosity thrust

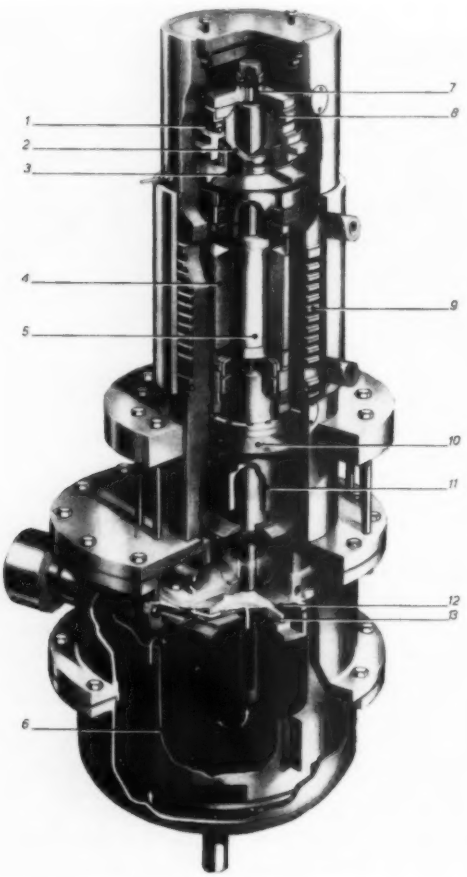


Fig 11 The Harwell gas bearing used in a liquid pump
1 Gimbal mountings. 2 Journal bearing. 3 Bearing support diaphragm. 4 Stator. 5 Rotor. 6 Baffle to ensure non-turbulent liquid surface. 7 Rotating thrust plate. 8 Stationary thrust plate. 9 Motor cooling jacket. 10 Bearing support jacket. 11 Journal bearing. 12 Mean liquid level. 13 Impeller

plate. This is because, during stopping and starting conditions, the gas film separating the two thrust faces breaks down and also during these conditions they have to accept the total weight of the rotating parts. High contact loading can then cause scuffing, local overheating and subsequent distortion of the optically flat faces. The use of a hydrostatic or pressure fed gas thrust bearing instead of the self acting type provides only limited improvement to the problem. It is however possible to obtain more normal load carrying capacity by having an arrangement where the thrust bearing is lubricated with a liquid instead of a gas. The thrust bearing can then be located near the impeller end of the shaft and the pumped fluid is used as the lubricant. In cases of slurry pumping it is necessary to provide a separate feed of compatible liquid free from solids. It may also be advantageous to use liquid lubrication for the bottom journal bearing if the side loading of the machine is high.

Although these arrangements are part way towards the all liquid lubricated bearings of the submersed and canned motor designs they have the added advantage of keeping the motor and its insulation away from the pumped fluid. In the case of liquid metals, slurries, etc., this is a very valuable consideration.

Conclusions

Each reactor proposal presents its own particular pumping problems, so that it is not possible to choose any one type of pump which provides the ideal solution for all reactors. All the factors of operating conditions, leak tightness, size and maintenance accessibility, have to be considered before it is possible to decide which design is the most suitable.

The pump manufacturer has now to concern himself with not only the hydraulic end of the unit, but also with the motor, bearings and where applicable the seal, so that the design can be conceived as a fully integrated unit.

During the next ten years or so the programme of installing nuclear power plant in the UK and abroad will provide the pump manufacturers with a challenge which, if it is to be met, requires them to direct a considerable effort towards the solving of the design, development and production problems associated with the manufacture of suitable pump units.

The latest UK programme of power by nuclear plant plans to have 5000 and possibly 6000MW of generating capacity installed by 1965. If 5% of the turbine output of this plant is allowed for pumping, a total of 250MW or 335,000 h.p. of reactor pumping equipment will be required in the next eight years. This estimate of horsepower requirements is definitely on the low side because, during the period when the gas-cooled Calder Hall type of reactors are being built, a 10-12% allowance of the turbine output for pumping would be more accurate.

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PUMP BUYERS' GUIDE

It is probably not an over-generalisation to assert that no nuclear energy plant can function without pumps of one kind or another. Many of these may be of perfectly standard design since they have to handle only non-active fluids, but for purely nuclear applications, very severe requirements of leak-tightness and long maintenance-free life demand mechanical engineering of a new order.

This Buyers' Guide is a survey in convenient tabular form of the products of the British pump industry. The number of pumps included suitable for handling active materials is not large compared with conventional units and this is indicative of scope for development. Further details of the pumps listed can be obtained by returning the reply-paid postcard facing page 298 to NUCLEAR POWER.

CLASSIFICATION OF PUMPS

BY TYPE

ROTODYNAMIC
CENTRIFUGAL
1 horizontal
2 vertical
3 multistage
GLANDLESS
4 canned motor
5 wet motor
6 submersible
7 self-priming
8 water ring
9 AXIAL FLOW
10 MIXED FLOW

POSITIVE DISPLACEMENT
RECIPROCATING
11 single cylinder
12 multi cylinder
13 variable delivery
14 diaphragm
15 metering
ROTARY
16 gear or lobe
17 screw or helix
18 vane

ELECTROMAGNETIC
CONDUCTION
19 a.c.
20 d.c.
21 INDUCTION

GAS CIRCULATORS
22 centrifugal
23 axial flow

BY USE

a Cold water
HOT WATER
b boiler feed
c circulation
d Sea water
e Condensate extraction
f Heavy water
CHEMICALS
g acid
h alkali
i organic
j Oils
k Slurries
l Semi-solids
LIQUID METALS
m solutions
n slurries

FIRM	USE	TYPE	CAPACITIES	PRESSURE OR HEAD	NOTES
W. H. Allen Sons & Co Ltd, Queens Engineering Works, Bedford	a, c, d	1	to 100,000 gpm	as required	
	a, c, d	2	to 100,000 gpm	as required	
	a, c, d	9	to 120,000 gpm	as required	
	a, c, d	10	to 120,000 gpm	as required	
George Angus & Co Ltd, Prince Consort Rd, Hebburn-on-Tyne	j	16	to 30 gpm	to 1500 psi	Oils only
Appleton & Howard Ltd, Salisbury St, St Helens	a, d, e, g, h, i, j, k, l	1, 2, 6	1-1000 gpm	to 250 ft	to 450°F All castable materials rubber and plastic lined. Special submerged design for hydrofluoric acid all concentrations.
Autometric Pumps Ltd, Maidstone, Kent	a, d	1			
	a, b, d, e, g, h, i	7			
	a, d, e, g, h, i	8			
	a, j	16			

FIRM	USE	TYPE	CAPACITIES	PRESSURE OR HEAD	NOTES
Barry Hill (Engineers) Ltd, Cheadle, Stoke-on-Trent	a, c, d	1	10-5000 gpm	20-400 ft	
	a, c, d	2	10-1500 gpm	20-600 ft	
	a, b, c, d	3	10-1000 gpm	to 2000 ft	
	a, d	5, 6	10-5000 gpm	to 1500 ft	
	a, c, d	7	10-600 gpm	to 150 ft	
	a, c, d	10	200-10000 gpm	to 100 ft	
British LaBour Pump Co Ltd, Blundell St, London, N7	a, c	1	to 1000 gpm	to 200 ft	Special alloys
	d, e	2			
	g, h, i j, k	7			
BSA Tools Ltd, Small Tools Divn, Montgomery St, Birmingham, 11	h, j, k	16	1½ to 20½ gpm	70 psi	⅜, ½, ¾, 1 in. gas pipe connexion
British Thomson-Houston Co Ltd, Rugby	m	19	2-200 gpm (linear type)	10-20 psi	to 500° C for Na, K, Hg, Bi, Pb
	m	20	to 10,000 gpm (linear type)	50-100 psi	to 500° C for Bi, Hg, Pb
	m	20	0-20 gpm (spiral type)	30-100 psi	to 500° C for Bi
	m	21	to 10,000 gpm (annular linear or reverse flow ann. lin.)	to 100 psi	to 500° C for Na, K or NaK
	m	21	0-10 gpm (spiral type)	30-100 psi	to 500° C for Na or NaK
David Budworth Ltd, Harwich, Essex	a, d	1, 2, 3	1-500 gpm	1-100 psi	Light alloy
	e	9	9-2000 gpm	9-16 psi	Fitted with air ejectors Gas turbine driven
The Candy Filter Co Ltd, 14 Church Rd, Hanwell, London, W7	g	13	0-3 gpm	to 5000 psi	Accuracy ± 1%
	h	15			
J. H. Carruthers & Co Ltd, Hamilton St, Polmadie, Glasgow	a, b c, d e, j	1, 2 7, 9 11, 12	to 2000 tons per hour	to 500 ft	
Cellulose Development Corporation Ltd, Hatch End, Middx.	a, c, d e g, h, i, k	1 2	50-3000 gpm	to 180 ft	
Clarke Chapman & Co Ltd Victoria Works, Gateshead-on-Tyne	a, b, c	11	5- 325 gpm	0- 250 psi	Steam driven
	a, b, c	12	26-325 gpm	0- 250 psi	Steam driven
	d	11	26-1120 gpm	0- 100 psi	Steam driven
	d	12	59-1495 gpm	0- 100 psi	Steam driven
	j	11	22- 650 gpm	0- 250 psi	Steam driven
	j	12	52-2800 gpm	0- 250 psi	Steam driven
	a, b, j	13	2- 250 gpm	0-5000 psi	Motor driven
	a, b, c, d	13	20- 740 gpm	0- 90 psj	Motor driven
	j	13	15- 700 gpm	0- 90 psi	Motor driven
	e	11	60- 600 lb/h	0- 25 psi	Steam driven
Coventry Climax Engines Ltd, Widdrington Rd, Coventry	a, d, f, j	1	500-750 gpm	200-350 ft	Automatic water ring primer
C. T. (London) Ltd, 27 Ashley Place, London, SW1 (representing Société Corblin of Paris)	a, c, d e, f, g h, i, j	14	0-2200 gph	to 4000 psi	Glandless and leakproof supplied to Dounreay for radioactive nitrogen and sodium vapour
Doulton Industrial Porcelains Ltd, Wilnecote Works, Tamworth, Staffs	g	14	6 gpm	15 ft	Hand operated
	g	1	40-350 gpm	20-160 ft	Stoneware impeller
The English Electric Co Ltd, Marconi House, Strand, London, WC1	m	21	26 gpm	21·4 psi	Na (ALIP type)
			150 gpm	17 psi	Na (FLIP type)
			400 gpm	16 psi	70/30 NaK Dounreay FLIP type
			1000 gpm	31 psi	Na (FLIP type)
			2500 gpm	30 psi	Na (FLIP type)
Fielding & Platt Ltd Atlas Works, Gloucester	a, j	12	55-136 gpm	1000 psi	Three-throw, totally enclosed
	a, j	13	9·4-29 gpm	6000 psi	Radial, multi-cylinder
			4·7-75 gpm	1000 psi	
			3·5-50 gpm	6000 psi	
Gilbert Gilkes & Gordon Ltd, Kendal, Westmorland	a, b, c, d	1, 3 7	2-200 gpm 2-50 gpm	0-100 psi 0-300 psi	
Girdlestone Pumps Ltd, 23 Davies St, London, W1	a, c, d, e, g, h	1	2-1000 gpm	5-150 ft	-50° to 250°F
	g, h, k	14	2-10 gpm	5-80 psi	Rubber lined
H. J. Godwin Ltd, Quenington, Cirencester, Glos	a	1	14-300 gpm	0-110 ft	
	a	1	1-18 gpm	30-240 ft	Shallow well jet conversion units
	a	1	4-14 gpm	90-180 ft	Deep well jet conversion unit
	a, b, c	11	2½-5 gpm	10-180 ft	200°F
	a, b, c	12	9-33 gpm	75-500 ft	200°F
	a, d, j	16	6½-13 gpm	5-100 ft	200°F

FIRM	USE	TYPE	CAPACITIES	PRESSURE OR HEAD	NOTES
Grease Appliance Co Ltd Romiley, Cheshire	j	11			Centralized oil lubricators for viscosities 12-380 cs
Gwynnes Pumps Ltd, 62 Chancellor's Rd, Hammersmith, London, W6	a, c, d	1, 2, 3, 9, 10	all sizes	to 1500 ft	
	g, h, i, j, k	1, 2	all sizes	to 100 ft	
The Harland Engineering Co Ltd, BEP Works, Alloa, Scotland	a, b, c, d, g, h, i, j, k, l, m, n	1	50-11,000 gpm	10-450 ft	b & c up to 300° C. All pumps can be supplied with Harland motors from 10 hp to 10,000 hp. Most can be supplied in stainless, or lined with glass, rubber etc.
	a, d, g, h, i, j, k, l, m, n	2	50-100,000 gpm	20-700 ft	
	a, b, c, d, j	3	50-1,700 gpm	80-4000 ft	
	a, c, f, m, n	4	50-6,000 gpm	20-200 ft	
	a, f	5	50-6,000 gpm	20-200 ft	
	a, d, f	6	50-1,000 gpm	50-1000 ft	
	a, g, h, i, j, k, l	7	300-10,000 gpm	60-200 ft	
	a, d	9	500-20,000 gpm	10-25 ft	
	a, d, k	10	200-20,000 gpm	40-200 ft	
Hathernware Ltd, Loughborough, Leics	g, h, i	1	6-600 gpm	to 100/120 ft	All contact parts in acid-proof stoneware.
Hamworthy Engineering Ltd, Poole, Dorset	a, b, c, d, e	1	to 700 gpm	to 350 ft	
	a, c, d	2	to 12,500 gpm	to 150 ft	
	a, c, d	6	to 250 gpm	to 120 ft	
	a, b, c, d, e	7			As 1, 2, 6 above
	j	16	to 4200 gpm	to 300 psi	
	j	17	to 2000 gpm	to 300 psi	
Hayward Tyler & Co Ltd, PO Box 2, Luton, Beds	a, b, c, d, f, g, h, i, j, k, m, n	1, 2, 3, 4, 5, 6, 7, 10, 11, 12	20 to 5000 gpm (Larger capacities if required)	Differential pressures up to 1700 psi System pressures Up to 3000 psi (standard range). Higher system pressures if required.	Process pumps up to 900° F
Hick, Hargreaves & Co Ltd, Soho Ironworks, Bolton, Lancs	e	1, 3	20-2500 gpm	40-300 ft	Single and 2-stage for power plant operation
Holden & Brooke Ltd, Sirius Works, Manchester, 12	a, c, d, g, h, j, k, l	1	to 5000 gpm	to 250 ft	L up to 600 gpm, 100 ft head
	a, g, h, j, k, l, m, n	2	to 5000 gpm	to 250 ft	L up to 600 gpm, 100 ft. m and n up to 1000 gpm, 100 ft.
	b	3	to 1000 gpm	to 1000 ft	Up to 250° F
	a, b, g, h, j, k, l	12	to 1300 gpm	to 5 tsi	
Hughes & Lancaster Ltd, Acrefair, Wrexham, Denbighshire	k	1	to 1800 gpm	to 160 ft	Used at Harwell and Aldermaston
	l	2			
Hydraulic & Mechanical Developments Ltd, 116 Victoria St, London, SW1	f etc.	1			Glandless by magnetic coupling
Hydraulics & Pneumatics Ltd, Wulfruna Works, Villiers St, Wolverhampton	j	12	1·5 gpm	2500 psi	
	j	13	1·5 gpm	2500 psi	
	j	16	1·5-3 gpm	2000 psi	
	j	16	4-12 gpm	1500 psi	
S. H. Johnson & Co Ltd, Carpenters Rd, London, E15	g	11	100-20,000 gph	100 psi	Diaphragm type used at Springfields
	h	12			
	k	13			
	l, n	14			
Kestner Evaporator & Engineering Co Ltd, 5 Grosvenor Gardens, London, SW1	c, d, g, h, k	1, 2, 7, 11, 12, 18, 22, 23 Glandless	2-750 gpm	to 250 ft	Constructional materials include Tantiron, Regulus Metal, Keebush, PVC, Stainless Steel, Cast Iron and rubber-lined Cast Iron to suit all acids
Kingsbourne Products Ltd, South Coast Rd, Peacehaven, Sussex	a, b, c, d, e, g, h, i, j, k	11, 13, 15	to 200 gph	to 175 ft	General purpose, low delivery. For all liquids below 250° C
The Leeds Engineering & Hydraulic Co Ltd, Union Crane Works, Rodley, Leeds	a, b, c, d, g, h, i, k, l	12	to 600 gpm	to 4500 psi	Stainless steel and other spec. mats. available
		13	to 600 gpm	to 4500 psi	

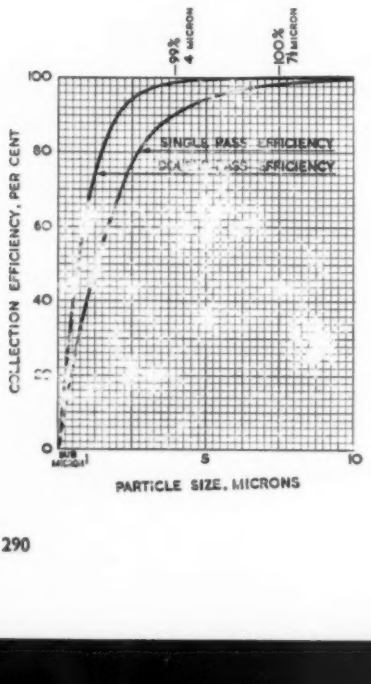
FIRM	USE	TYPE	CAPACITIES	PRESSURE OR HEAD	NOTES
Lee, Howl & Co Ltd, Tipton Engineering Works, Tipton, Staffs	a, b, c, d, e, f g, h, i j, k, l	1, 2, 3 7, 8, 10 11, 12, 13 14			
Liquid Systems Ltd, Union Rd, Croydon, Surrey	a, d, e, h, i, j	18			
Arthur Lyon & Co (Engrs) Ltd, Park Works, Stamford, Lincs	a	1	10-7500 gpm	to 150 ft	Self priming
E. N. Mackley & Co, Hawks Rd, Gateshead, 8	a, c, d, f, h, j, k, l	1, 2	10-15,000 gpm	to 200 ft	Special materials to suit requirements
	a, b, d	3	10-2500 gpm	to 2500 ft	
	a	11, 12	20-300 gpm	to 300 psi	
Charles S. Madan & Co Ltd, Vortex Works, Broadheath, Altrincham	j l a, etc	compressed air operated		20-55,000 psi 14000 psi 1:1 air pressure	For hydraulic test For high viscosity For thin liquids
Measurement Ltd, Tameside Factory, Dobcross, Oldham	j	11 12 13 16	10-2300 gpm 10-2300 gpm 10-2300 gpm 10-2000 gpm	75 psi 75 psi 75 psi 400 psi	'Rotoplunge'—rotary with reciprocating piston. To 250° F
Merrill Pumps Ltd, Cavendish Rd, Sheffield, 11	f, g, h, k	11 14	to 75 gpm	to 150 psi	A wide variety of contact materials available
Mirrlees (Engineers) Ltd, Earl Haig Rd, Hillington, Glasgow, SW2	j	17	½-2000 gpm 2-100 gpm	150 psi 2000 psi	"Imo" screw pump
L. A. Mitchell Ltd, 37 Peter St, Manchester, 2	g h k	1 14 14	to 1200 gpm 350 gph 600 gph	100 ft 30 ft 30 ft	Corundum linings Hand operated Motor driven
Mono Pumps Ltd, Mono House, Sekforde St, London, EC1	a, g, h, i, j, k, l	17	to 100 gpm	to 130 psi	Used on uranium extraction and activated sludges
The National Boiler & General Insurance Co Ltd, National Buildings, St Mary's Parsonage, Manchester, 3	a	Test pump		to 10,000 psi	Hand operated
Ormerod Engineers Ltd, Hollows Works, Shawclough, Rochdale	a, d, g, j	13 15	to 1000 gph	50 ft	Viscous liquids, Metering, Homogenizing
The Palatine Tool & Engineering Co Ltd, 64-76 Brighton Rd, Surbiton, Surrey	m, n	19	10 gpm	14 psi	On Na. Used at Harwell, Culcheth and in industry
The Pulsometer Engineering Co Ltd, Nine Elms Iron Works, Reading, Berks	a, c, d	1, 2, 3, 6, 7, 8, 9, 10, 12, 13, 14	to 30,000 gpm	to 3600 ft	
	b	1, 2, 3	to 2000 gpm	to 4000 psi	
	e		all duties		
	g, h,i		all duties		Stoneware lined or sp. mats.
	j		all duties		Complete refinery requirements
	k		all duties		Used for coal washing
	l		18,000 gpm	all duties	
Ransomes and Rapier Ltd, Ipswich	a, c, d, e, k, l	7	4000-18,000 gph	to 150 ft	Petrol, diesel, electric or independent drive
Rhodes, Brydon & Youatt Ltd, Waterloo Engineering Works, Gorsey Mount St, Stockport	a, c	2	6-120 gpm	6-13 ft	Pipeline mtg. To 220° F, mech. seal
	a, c	2	26-500 gpm	4-20 ft	Floor mtg.
	a	2	14-25 gpm	20 ft	Free standing, sump
	a, c, d g, h, i, j	2	to 4000 gpm	120 ft	Suspended type
	e	1	to 1500 gpm		
	c	1	to 1000 gpm	to 150 psi	To 350° F, water cooled
	c	2	to 500 gpm	350 psi or more	To 430° F, water cooled
	a, c, d, e, g, h, i, j	1	5-300 gpm	5-140 ft	To 220° F, unit const.
	g, h, i, j	1	to 300 gpm	to 100 psi	To 700° F
	a, b, d, e	7, 8, 3	3-33 gpm	50-80 ft	Not glandless
	m	2	to 100 gpm	40 ft	To 1560° F. Also for fused salts
Safran Pump Division, Saunders Valve Co Ltd, Drayton St, Wolverhampton	a, b c	1, 3 2	various to 110 gpm	12 ft	
Thomas Savery Pumps Ltd, Newcomen Works, Bracebridge St, Birmingham, 6	j	13, 15	to 150 gph	to 1500 psi	
Sealed Motor Construction Co, Bristol Rd, Bridgwater, Somerset	a	4, 6	to 435 gph	to 170 ft	

FIRM	USE	TYPE	CAPACITIES	PRESSURE OR HEAD	NOTES
Sigmund Pumps Ltd, Team Valley, Gateshead, 11	a	1, 2, 3	10-40,000 gpm	200 psi	
	b	3	2000 gpm	1200 psi	
	c	1	4000 gpm	800 psi	
	d	1, 2	20,000 gpm	100 psi	
	e	1	2000 gpm	150 psi	
	g	1, 2	1500 gpm	100 psi	
	h	1, 2	2500 gpm	100 psi	
	j	1	to 5000 gpm	1000 psi	To 800° F
	k	1, 2	5000 gpm	50 psi	
	l	1	2000 gpm	40 psi	
G. E. Simm (Engineering) Ltd, 27 Broomgrove Rd, Sheffield, 10	a, b	1, 14	125,000 gph	110 ft	
Spenborough Engineering Co Ltd, Valley Works, Union Rd, Heckmondwike, Yorks		12	1-15 gpm	to 2000 psi	Oil operating
		18	1-6 gpm	to 1500 psi	
Stein Atkinson Vickers Hydraulics Ltd, 60 Buckingham Palace Rd, London, SW1	j	18	1-60 gpm	1000 psi	For fluid power transmission
Sumo Pumps Ltd, Crawley, Sussex	a, d	3, 4	100-50,000 gph	to 950 ft	
	k	6, 10			
Henry Sykes Ltd, Southwark St, London, SE1	a, c, d, g, h, i, k, l	1, 2, 7	to 3500 gpm	to 100 psi	
	a, c, d, g, h, i	3	to 1000 gpm	to 250 psi	
	a, k, l	11	to 150 gpm	to 30 psi	
	a, d, k, l	14	to 200 gpm	to 20 psi	
Tangyes Ltd, Pumps Division, Smethwick, Birmingham	a, b, c, d, e, g, h, i, j, k, l	1, 2, 3, 9, 10, 11, 12	to 12,000 gpm	to 500 ft	
Tecalemit Ltd, Plymouth and Brentford					Oil and grease pumps for all forms of lubrication and the handling of lubricants
Tubela Engineering Co Ltd, Fowler Rd, Hainault, Ilford, Essex		12, 13	0·5-3·0 cu. in. per pump stroke	to 3000 psi	Hand operated for bending, testing etc
Varley-FMC Ltd, Ferry Lane, Brentford, Middx	a	2, 3, 12	60-2000 gpm	to 400 psi	Deep well
	j, k	16, 17, 18	0·5-200 gpm	to 600 psi	
Wayne Tank & Pump Co Ltd, Wayne Works, Newlands Park, London, SE26	h, j	1	to 220 gpm	20 psi	Self-priming. j for low viscosity only
	h, j	16	20-125 gpm	to 100 psi	
G. & J. Weir Ltd, Cathcart, Glasgow, S4	b	1, 3	10,000 gpm	5000 psi	To 550° F
	b	2, 3	1000 gpm	1000 psi	To 250° F
	c	1, 2	5000 gpm	100 psi diff. press.	To 600° F
	c, f	4	3000 gpm	100 psi	To 600° F
	j	1, 3	1000 gpm	2000 psi	To 750° F
		22	6000 cfm	30 psi	
	e	1, 2, 3, 4	2000 gpm	100 psi	
	b	11	350 gpm	300 psi	Vertical steam-driven
			100 gpm	650 psi	
	a, c, d, e, g, h, j	11, 12	750 gpm	90 psi	Vertical steam-driven and motor-driven 2-throw
	b, c, j	12	1000 gpm	3000 psi	3-, 5- and 7-throw
	a	12	5 gpm	10,000 psi	Hydraulic 3-throw
Wilkinson Rubber Linatex Ltd, Camberley, Surrey	g, h, k	1, 2	15-3000 gpm	to 120 ft	Rubber linings
	g, h, k	14	2-8 gpm	to 30 ft	Rubber linings
Williams & James (Engineers) Ltd, Chequers Bridge, Gloucester	a, b	12, 13	to 10 gpm	to 400 psi	
Edward Wilson & Son Ltd, Aintree Rd, Bootle, 20, Lancs	a, h, k, l	1, 12	10-500 gpm	15-40 ft	
Worthington-Simpson Ltd, Newark, Notts	a, d	1	to 75,000 gpm	60-300 ft	
	e		to 1200 gpm	40-300 ft	
	g, h, i		to 1000 gpm	35-200 ft	
	k, l		100-2000 gpm	35-150 ft	
	a, d	2	to 18,000 gpm	40-300 ft	
	e		to 1200 gpm	50-300 ft	
	a, d	3	to 3000 gpm	150-1000 ft	
	e		to 1200 gpm	50-300 ft	
	a, d	7	to 2000 gpm	20-200 ft	
	a, b, c, d	8	to 30 gpm	100-600 ft	
	e		to 14 gpm	50-150 ft	
	a, d	9	2000-17,000 gpm	10-30 ft	
	a, d	10	1500-30,000 gpm	10-30 ft	
	a, b, c, d, e, h, j, k	11	to 7000 gph	to 10,000 psi	Steam-driven
	a, b, c, d, h, j, k	12	to 40,000 gph	to 10,000 psi	Steam-, electric- or engine-driven
Wright Electric Motors (Hx) Ltd, Century Works, Pellon Lane, Halifax	a, b, c, e	1	10-500 gpm	20-200 ft	Motorized

2-stage cyclones for reactor systems

A two-stage dust extraction unit for carbon dioxide coolant in power reactors has been introduced by Mancuna. Known as *Dustex* D 450, it is mechanical, requires no maintenance, has no moving parts or replacement cells, and can therefore be enclosed within a permanent biological shield. Capable of handling a gas volume of 20 lb/s at 180-200°C at 140-160 psi, it is claimed to remove 99 per cent of entrained dust particles. Pressure vessel is 3 ft 8 in. dia. and overall height 8 ft 3 in. The collecting cells consist of 4½ in. dia. cyclones of machined and polished meehanite in two stages. First stage at low pressure removes the dust down to approximately 10 microns, and the second, high pressure stage, down to 4 microns. The unit prevents the dust burden building up to a detectable amount.

The Mancuna dust collector for CO_2 circuits can be permanently inside the shield. Collection efficiency is given below



Mancuna Engineering Ltd,
Denton, Manchester

Demineralized water from portable plant

Distilled quality water without use of heat or power can be obtained from the new mark V portable *Deminrolit* plant by Permutit. Incorporating a dial type conductivity tester and supplying up to 6 gallons of pure water hourly, this is particularly suitable for laboratory and small process work.

Basically the plant consists of two columns of ion exchange material. When raw water is passed through the first column containing Permutit *Zeo-Karb* cation exchange mineral, the mineral salts in the raw water are converted to their corresponding acids. These acids are then passed down through the second column containing *De-Acidite* ion exchange material which absorbs the acid. The demineralized, or de-ionized, water which results from this process is of distilled quality.

The *Deminrolit* is easy to operate, and the only running costs involved are the small quantities of acid and alkali required for regenerating the ion exchange materials.

The Permutit Co Ltd,
Permutit House, Gunnersbury Avenue,
London, W4

X-ray spectrometer uses servo system

One of the difficulties in using X-ray spectra for the analysis of materials is measuring the intensity of the spectrum lines and thence to record the quantitative or qualitative result. Solartron claim to have eliminated this drawback with their automatic X-ray spectrometer.

A continuous X-ray spectrum is directed from an X-ray tube on to the sample or specimen. The reradiated X-rays of specific wavelength from the sample are passed through a crystal, which acts as a diffraction grating and produces a line spectrum, the diffracted rays being collected and collimated. The proportional intensities of the spectra enable the percentage of the elements present to be computed. The detector, in the form of a geiger counter, proportional counter or scintillation counter, is automatically moved through the spectrum produced. It recognizes and measures the intensity of each line. The X-ray tube and the specimen are held in a fixed position and the crystal and detector are rotated through the angles θ and 2θ respectively.

For the detection of expected impurities as in metals and alloys, chemicals, minerals, liquids and gases in oil refinery processes and chemical processes, the crystal and detector are pre-programmed by a servo system to align themselves on the spectra of these impurities.

The intensity of the spectrum lines is measured either by taking a count of the electrons produced in the counter over a fixed time period or by the comparative measurement of all the lines. The results may be presented graphically on a pen recorder or automatically printed out on a tabulating machine.

The Solartron Electronic Group Ltd,
Thames Ditton, Surrey

New winding wire is flexible, heat stable

Teramel is the name given to a new synthetic-enamelled winding wire which BICC have recently developed to solve problems set by a variety of electrical equipment. The insulant is a polyester-resin-based synthetic enamel possessing excellent electrical and mechanical properties and in particular a high thermal stability, giving it a long life at high temperatures—it may be used continuously at temperatures of up to 130°C. Thermoplastic flow is negligible and it has a high resistance to abrasion. It is hard and adheres strongly to the copper, but it is flexible and the wires can be stretched, twisted and even flattened without damage to the film. The enamel also has good dielectric properties and a high space factor.

Almost any impregnating varnish may be used on the finished windings as *Teramel* enamel is highly resistant to solvents. However, for optimum life at high temperatures, the use of silicone varnishes is recommended.

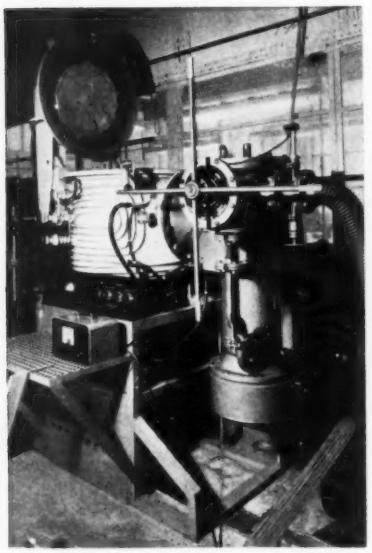
British Insulated Callender's Cables Ltd,
Norfolk House, Norfolk Street,
London, WC2

Vacuum furnaces heated by graphite bars

Graphite resistor furnaces capable of providing temperatures up to 3000°C have been developed by GEC to meet the demand created by development work on atomic energy, guided weapons, and supersonic aircraft, and for high temperatures required in the heat treatment of titanium, tantalum and zirconium, for sintering, and for brazing components which will operate at elevated temperatures.

The body of the furnace is a water-cooled, vertical, cylindrical steel tank with a hinged, domed lid, a vacuum-tight seal being formed between flanges on the lid and the furnace body. The charge is heated by radiation from a triangular-shaped assembly of graphite bars which surrounds the charge space. These graphite bars operate at a low voltage supplied by a three-phase transformer. A voltage regulator enables the secondary voltage of this transformer to be steplessly varied to give control over the heating rate.

Radiation screens consisting of molybdenum sheets so arranged as to enclose



One of the first of the new GEC furnaces is at BSA Group Research Powder Metallurgy Laboratory

the heating chamber, provide the thermal insulation. With the furnace lid raised the top radiation screen can be lifted to give access to the chamber. The charge is supported on a graphite tripod.

The vacuum pumping system consists of a gas ballast pump, a combined booster and oil diffusion pump, and a valve block which controls the evacuation of the furnace chamber. An operating vacuum between 10^{-4} mm and 10^{-5} mm Hg can be obtained.

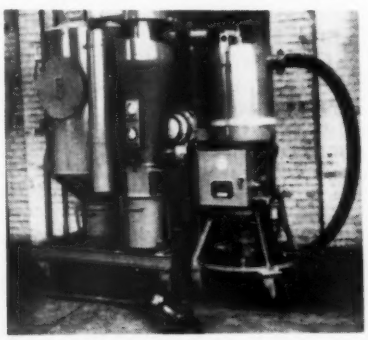
Safety devices give protection of both the furnace and the charge against possible failures in the electric and water supplies.

Maximum rating of the furnace is 120 kVA. The furnace will take a charge approximately 9 in. diameter and 12 in. high with a maximum weight of 90 lb, and with an alternative element arrangement the charge space can be increased to 11 in. diameter by 11 in. high.

The General Electric Co Ltd,
Magnet House, Kingsway, London, WC2

Closed circuit grit-blasting on DFR sphere

The extreme durability required of the Dounreay sphere demanded careful preparation of the 19ft by 10ft steel plates, prior to the application of the protective coating. It was decided that they should be grit blasted and metal sprayed prior to fabrication, leaving a 12 inch welding strip round the edges of each plate. Whilst it is possible to metal spray *in situ*, surface preparation by conventional grit blasting methods was impracticable The problem was solved by using the Vacu-Blast closed circuit system of shot-blasting in which the crushed iron grit is



Grit blasting may be done 75 ft from the machine

supplied to a special gun through flexible hoses, and the gun applied selectively to the work surface.

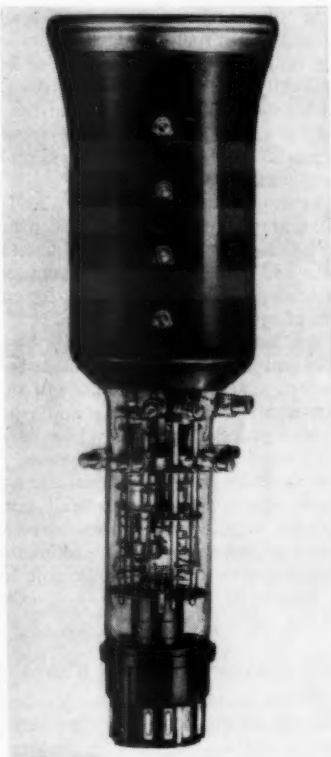
The machine comprises a self-contained grit blasting unit usable both in the open and in the workshop. At Dounreay it was necessary to raise the machine as work progressed and the whole blast unit was sited on scaffolding. The operators were free to work at a distance of 75ft from the blast gun to the machine. Three standard machines were used at Doureay, working in the open throughout the construction period. Vacu-Blast has also been used in a variety of applications at Aldermaston, Harwell, Calder Hall and Chapelcross.

Vacu-Blast Ltd,
291 Aberdeen Avenue,
Slough, Bucks

Double gun CRT has minimum distortion

The need for good deflexion sensitivity in high writing speed cathode ray tubes has led to a new addition to the 20th Century range of multi-gun tubes.

This is a double-gun tube with a post deflexion accelerating system suitable for operation at high ratios of screen to anode voltage. The gun itself is identical in characteristics to those used in the D6 series of tube, maintaining the features of high precision and high beam current. The configuration of the accelerating



The tube has a 6½in. flat face

electrode minimizes the distortions associated with PDA systems in a double-gun tube and allows the tube to be operated with a ratio of screen to gun voltage of 5:1, whilst keeping deflexion non-linearity to less than 3 per cent. Deflector sensitivities at an overall voltage of 10 KV are 0·25 mm/V, giving a deflexion sensitivity of one volt per spot width with a spot diameter of 0·25 mm.

The tube has a 6¼ in. diameter, ground and polished flat face and is 19 in. long overall. For operation in the region of 10 to 20 KV aluminized screens are provided. The screen material is normally blue, for photographic purposes, but alternatives may be supplied to special order.

20th Century Electronics Ltd,
King Henry's Drive, New Addington,
Croydon, Surrey

How the nuclear and generation sides of a power station are integrated

System control and operation

W. MACRAE, MSc, AMIEE
Chief Electrical Engineer Nuclear Power Plant Co Ltd

IN CONVENTIONAL power stations, power control is effected by manual adjustment of the turbine governor valves or automatically by system frequency variations. Increase in power demand is reflected in fall of steam pressure. This is corrected by adjustments made to the boiler draught and fuel feed to restore normal pressure. Thus, the boilers follow the power demand of the turbines and indirectly that of the power system. The governor characteristics of all the turbines on the system are similar, so that changes in system load (apart from characteristics imposed by the distribution system) are shared by all the machines.

In the Calder Hall stations, the steam fed from the turbines is regulated by pressure controlled 'spill-over' valves and the power generated is dictated by the steam available and not by the power demand. Thus, the reactor is in control and the plant delivers constant power irrespective of system demand.

At Calder, where power is a by-product, this is acceptable and in fact desirable. To use such a scheme in nuclear stations on a power system will mean that they will not participate in load sharing and will not contribute to the stability of the system. When they supply only a small portion of the load on the system, the effect will be small, but as more come into operation the effect will become more pronounced. An overall control system for such stations with characteristics similar to those of conventional plants, should be the ultimate aim. It will also be of considerable advantage to be able to control these stations in essentially the same way as conventional stations, i.e. via the turbine governors.

Basis of an overall control scheme

Turboalternators

The use of the dual steam pressure cycle with the Calder type power reactors enables higher thermodynamic efficiencies to be achieved than with a single pressure cycle, but it requires the turbines to be fitted with two sets of control valves, one for the h.p. section and one for the l.p. section. As the ratio of the h.p. and l.p. steam to the main turbines may not be constant over the working range, particularly if auxiliary plant such as the reactor gas circulator drives be driven off one steam line only, the relative settings of the h.p. and l.p. valves are a function of load. With pressure control as at Calder Hall, they adjust themselves automatically, but if they were both on governor control, the adjustment of the valves to maintain the steam pressure in both sections of the boiler sensibly constant would be very involved. A satisfactory compromise is to have the h.p. section of the turbine on governor control and the l.p. section on pressure control. All the power adjustments can then be initiated at the h.p. governor valve and be reflected in the h.p. section of the steam-raising plant. The flow of steam in the l.p. section will then adjust itself automatically. In practice the turbine valves can be easily made to operate on either pressure or governor control giving three modes of operation as shown in the following table.

ALTERNATIVE	h.p.	l.p.	UTILIZATION
1	Speed	Speed	for synchronizing essentially
2	Pressure	Pressure	
3	Speed	Pressure	normal operation

Reactor

The essential requirements of any particular scheme for the reactor are that:

a. the coolant outlet temperature be kept within close limits
b. the mass flow of the coolant be sensibly proportional to power
c. satisfactory operation be maintained irrespective of changes in reactor constants due to build-up of poisons or ageing of the fuel

It is also necessary to keep the coolant inlet temperature to the reactor within limits although not such close limits as that of the outlet temperature. Control of the coolant temperatures maintain the steam conditions sensibly constant and keep the thermal cycling within the reactor to a minimum.

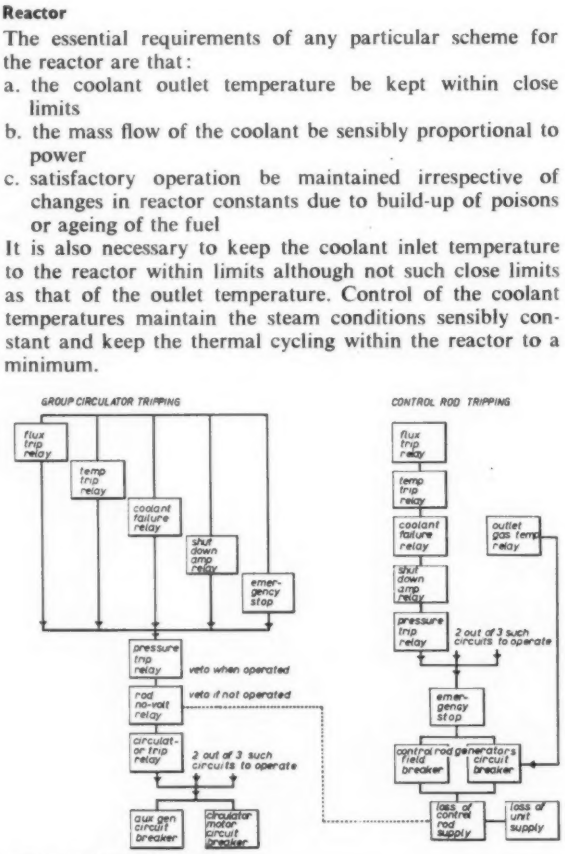


Fig 1 Typical trip circuits

The means available for controlling the reactor power are the control rods and the flow of coolant. Withdrawal of the control rods causes an increase in power but also a change in temperature which, because of the negative temperature coefficient, tends to cancel the reactivity released by the rods. Similarly an increase in the coolant flow causes the reactor temperature to fall, releasing reactivity and the power to increase until the conditions are sensibly restored. Thus if the control rods are used for power control, the mass flow must be adjusted to keep the temperatures constant and vice versa. Hence there are two possible control schemes. As both control rods and coolant flow affect the power and temperature, in any control scheme there will be interaction between them,

but by suitable choice of control rates stable operation can be achieved. Either or both controls can be automatic or manual. For overall station control under normal conditions full automatic control is desirable but means must of course be provided for manual control in emergencies and for start-up.

Experience at Calder Hall and simulator studies have shown that of the alternatives reactor power control by coolant flow is the most suitable for integration with overall control of the station. The role of the control rods is then to maintain the coolant outlet temperatures sensibly constant and to compensate for changes in reactor constants.

Various ways of indicating changes of power demand to the reactor section are possible but the simplest is change of steam pressures and steam flow. Of these, the most convenient is steam pressure. Thus in an automatic control scheme, steam pressure and reactor coolant temperatures can control coolant flow and control rods in either combination.

Safety

It is now generally accepted that the gas cooled graphite-moderated reactor does not present any hazard to the general public. Equally important, although not generally appreciated, is the fact that by careful design, it can be arranged that the reactor will not suffer serious damage due to the failure of its control or main cooling systems. The prime consideration in this respect is the prevention of excessive fuel temperatures. If at any time the ratio of the heat output to coolant flow exceed the design value, overheating of the fuel will occur. An increase in this ratio can be due either to an increase in heat output or to a decrease in coolant flow. It is essential that under either condition the rise in fuel temperature be a minimum.

Elaborate systems of protection are provided to ensure immediate reactor shut-down following such incidents as failure of the main circulators, excessive coolant pressure, excessive fuel temperature and excess power level. A block schematic diagram of the trip circuits for a typical reactor is shown in Fig 1. All the trip circuits are in triplicate and operate on the two-out-of-three principle. This assures a high degree of reliability and minimizes the incidents of spurious trips due to faults in the tripping system. The reliability of the control rod actuating mechanism is also of great importance and rigorous proving tests of these are essential. However, when considering the inherent safety of the reactor, the reliability of the protection system cannot be assumed.

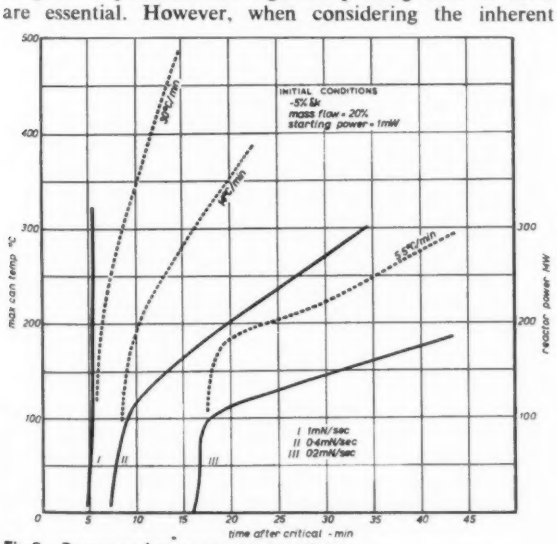


Fig 2 Power and temperature transients

When discussing reactor control it was pointed out that withdrawal of control rods or increase in coolant flow increases the reactor power. The increase in power is always slightly less than that in coolant flow so that overheating does not occur. For example increasing the flow from 20 per cent to the design value only increases the power to approximately 80 per cent of the design value. This is a characteristic of Calder type reactors with the large thermal inertia of the moderator. In order to limit power and temperature surges due to maloperation during start-up, the rate of withdrawal of the control rods must be strictly limited. Power and temperature transients computed for various rates of withdrawal for a typical reactor are shown in Fig 2. It will be seen that the negative coefficient of reactivity limits the power surge as soon as the fuel temperature comes appreciable. When the rods are withdrawn at the design point the temperature coefficient is immediately effective and reduces the net reactivity released to about half that released by the rods. A rate of withdrawal of approximately 0·2 mN/sec gives a tolerable start-up transient and a reasonably slow uncontrolled increase of power at the design point.

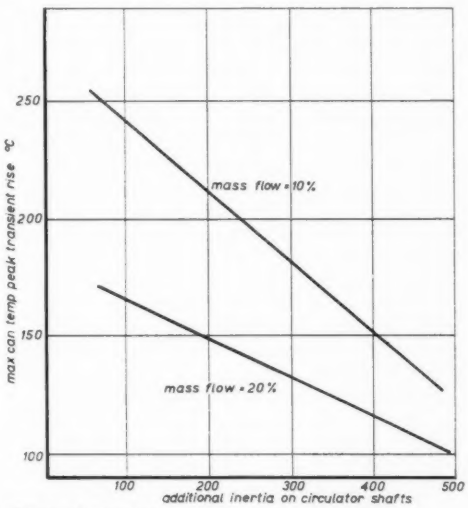


Fig 3 Effect of circulator intertia on can temperatures

Reduction of coolant flow due to failure of the main circulators would cause a more rapid rise in fuel temperature than that due to the limited rate of control rod withdrawal if the reactor power were not reduced immediately. A reactor trip following circulator failure reduces the power sufficiently rapidly to prevent a rise in fuel temperatures. However, should the reactor fail to trip on loss of the main circulators, the fuel and coolant temperatures will rise at an initial rate of the order of 3°C/sec. This is probably the most serious fault condition that can influence the design, the transients being dependent on three main factors:

a. the negative uranium temperature coefficient
b. the run-down time of the main circulators
c. the capacity of the standby coolant plant and the natural circulation inherent in the coolant circuit design.

The rate of fall of flow on failure of the main circulator drives can be reduced by increasing the inertia of the circulators with flywheels coupled to their shafts. The effect on the maximum fuel temperature is shown in Fig 3.

The provision of auxiliary circulator drives which auto-

continued on page 297

NUCLEAR POWER's new series continues with protection from external radiations

Basic Health Physics—2

D. E. BARNES, GM, BSc. AMIEE, AInstP
Superintendent Health Physics, AWRE, Aldermaston

THE MAXIMUM PERMISSIBLE LEVEL (mpl) for exposure to radiation from external sources is 300 m rem per week, as was stated in last month's article. This is the basic level which applies to the body as a whole, and when expressed in this way is applicable to all kinds of ionizing radiations and to doses due either to one type of radiation or to a combination of different types of radiation. In the latter case the doses due to each type must be added together after due allowance has been made for their RBE factor. It should be noted that all doses which affect the same volume of tissue are additive, so that if, for example, some part of the body is receiving radiation from an internal source, the permissible dose of external radiation is correspondingly reduced.

This basic dose of 300 m rem per week is modified so as to permit a larger dose in circumstances when only part of the body is receiving the increased dose.

For the skin there are two levels depending on the penetrating power of the radiation. A dose of 600 m rem to the skin due to moderately penetrating radiation is permissible provided the dose in the tissue at 5 cm depth is not more than 300 m rem. For radiation of very low penetrating power (HVL less than 1 mm of water) a skin dose of 1500 m rem per week is permitted. Also exposure of the hands and forearms, the feet and ankles, the head and neck (but excluding the lens of the eyes) may be increased to 1500 m rem per week surface dose provided the radiation is of such a nature that the dose to deeper tissues is less than that at the surface.

Although the above basic dose expressed in rem is applicable to all radiations, the case of neutrons has been dealt with separately and has been expressed in two ways: either a dose of 30 m rad per week measured at a depth of 2 cm, or an exposure to one, or a proportionate amount of two or more, of the following fluxes:

neutron energy	flux n/cm²/sec*
0·025 eV (thermal)	2000
10 eV	2000
10 KeV	1000
0·1 MeV	200
0·5 MeV	80
1 MeV	60
2 MeV	40
3–10 MeV	30

*Whenever dose-rates are quoted a working week of 40 hours is to be assumed.

It is sometimes convenient to use the concept of flux in gamma-radiation calculations and, though the International Commission on Radiological Protection do not in this case make their recommendations in this form, the flux per rad for various energies can be calculated from the true absorption coefficient, that is omitting scattering or conversion coefficients.

The flux is given by the expression:

$$\phi = \frac{100}{\sigma_a/\rho \times 1{\cdot}6 \times 10^{-6} \times E}$$

Where ϕ = photons/cm²/rad
100 = ergs/rad
σ_a/ρ = true mass absorption coefficient for the medium in cm²/gm
$1{\cdot}6 \times 10^{-6}$ = ergs/MeV
E = energy of photons in MeV

A curve relating flux per rad in air to photon energy calculated in this way using values of true absorption given by Gladys White[3] is reproduced in figure 5. Flux per roentgen may be obtained by multiplying flux per rad in air by 0·84 $\left(\text{i.e. } \frac{83{\cdot}8}{100}\right)$

Radiation output from various types of sources

The output from X-ray sets depends on the exciting voltage, the tube current and to some extent on the wave-form given by the high tension generator and the design of the X-ray tube. The exciting voltage is usually expressed in kilovolts peak (kVp), since this determines the hardest

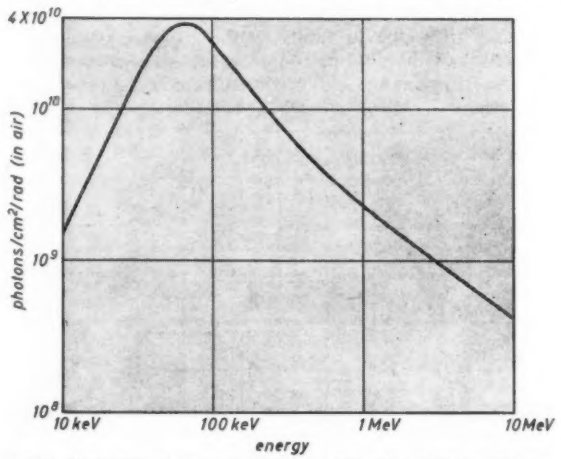


Fig 5 Variation of gamma-radiation flux with photon energy

radiation from the tube, whilst the current is measured in milliamperes. Except at very high energies, most of the energy appears as heat in the anode and the efficiency of X-ray production is very small, ranging from a fraction of one per cent at energies below 200 kVp up to a few per cent in the 1-2 MVp region. At high energies, in the 20 MVp region, it rises to some 50% or more.

Typical values for the output per milliampere measured at one metre from the anode from the normal type of X-ray equipment are given in the table below.

exciting voltage kVp	50	70	100	150	200	250	300	400	1000
output r/min/mA at one metre	0·2	0·4	0·6	1·3	1·8	2·5	3·5	7·0	18
output ÷ mpl	160	320	480	1040	1440	2000	2800	5600	$1{\cdot}4\times10^4$

It should be noted that in the case of crystallographic equipment the inherent filtration is kept very low and the distances from the anode are very short resulting in extremely high intensities which in very short exposure times could lead to skin damage or burns. For this reason, users are warned never to risk putting fingers into the beam and always to make manipulations either with the radiation off or, if this is impracticable, by means of forceps.

With gamma-ray sources the dose-rate can be calculated from the photon output using the relationship between photon flux and dose given in figure 5. It is, of course, necessary to take account of the number of photons per disintegration and their energy. An extensive body of such data has been collected and published by the US National Bureau of Standards[4] and later work can be found by reference to Nuclear Science Abstracts[5].

The dose-rate from a gamma emitting isotope is given by the expression

$$d=\frac{Q\times 3{\cdot}7\times10^{10}\times3600}{4\pi l^2}\times\sum\left(\frac{N_E}{p_E}\right)$$

$$=1{\cdot}06\times10^{13}\,\frac{Q}{l^2}\sum\left(\frac{N_E}{p_E}\right)$$

Where d = dose-rate in r/hr
Q = quantity of isotope in curies
l = distance from source in cm
N_E = number of photons/disintegration of energy E (note that N may be fractional in certain cases)
p_E = photons/cm²/r at energy E
$\sum\left(\frac{N_E}{p_E}\right)$ = sum for all the various energy levels emitted

Taking as an example the cobalt isotope Co-60, the decay scheme shows that two gamma photons, of energies 1·17 and 1·33 MeV, are emitted in cascade at each disintegration. Since there is only one photon of each energy, N is one; $p_{1\cdot17}=0{\cdot}84\times2{\cdot}0\times10^9$ and $p_{1\cdot33}=0{\cdot}84\times1{\cdot}8\times10^9$. If we consider the dose-rate at one metre from a one curie source of this isotope the formula becomes:

$$d=1{\cdot}06\times10^{13}\times\frac{1}{10^4}\left(\frac{1}{1{\cdot}68\times10^9}+\frac{1}{1{\cdot}51\times10^9}\right)$$

$$=\frac{1{\cdot}06\times10^{13}\times3{\cdot}2}{10^4\times10^9\times2{\cdot}54}$$

$$=1{\cdot}33\text{ rhm/curie}$$

Table II gives data for a number of commonly used gamma-emmitting isotopes.

The dose-rate from beta emitters is difficult to calculate with great accuracy since it is complicated by absorption in air and by the possibility of back-scatter and *Bremsstrahlung* from the support or container.

Neglecting these factors the expression

$$d=\frac{10^6\,Q\,n}{3\,l^2}\text{ rad/h}$$

where d = dose-rate
Q = quantity of isotope in curies
n = number of beta-particles per disintegration
l = distance from source in cm

gives an accuracy within ± 10% for E_{max} over 1·5 MeV. Below 1·5 MeV the dose at short distances will be progressively greater with decrease of energy and at about 0·3 MeV is twice the value given by the expression. However, air absorption increases with reduction in energy and at moderate distances this will tend to compensate. At a distance of 15 cm, this compensation is good down to about 0·4 MeV, but at greater distances absorption predominates and the dose from lower energy sources falls away rapidly. Above 1·5 MeV the expression is still good for distances up to 30 cm, after which there is some reduction especially at the lower end of the energy band, until at one metre the dose-rate is less by a factor of 1·5-2.

Table II

element	isotope	half-life	γ-energy MeV	rhm/curie
Sodium	Na-24	15 h	2·76, 1·38	1·93
Iron	Fe-59	46 d	1·3, 1·1	0·65
Cobalt	Co-60	5¼ y	1·33, 1·17	1·33
Iodine	I-131	8 d	0·36, 0·64	0·29
Caesium	Cs-137	33 y	0·67	0·32
Lanthanum	La-140	1¾ d	0·3, 0·5, 0·8, 1·6	1·2 Complex spectrum
Thulium	Tm-170	129 d	0·084	$3{\cdot}5\times10^{-3}\gamma$ in 10% of disintegration only
Tantalum	Ta-182	111 d	1·2	0·62 Complex spectrum Many lines in 0·1–0·3 region
Iridium	Ir-192	70 d	0·3, 0·5, 0·6	0·27
Gold	Au-198	2¾ d	0·41	0·25
Radium + daughters		1600 y	—	0·85 Complex (see fig 3, NP, June, p 251)

The dose-rate in handling a beta emitter, the surface-dose, may be calculated as follows. Consider first an infinite volume of beta emitting substance having a specific activity, that is activity per unit mass, of A curies/g; by the principle of conservation of energy an equilibrium must arise so that the amount of energy absorbed in any volume of the medium is the same as the energy being generated in that volume. Hence the dose within the medium is:

$$d=\frac{1{\cdot}60\times10^{-6}\times\bar{E}\times3{\cdot}70\times10^{10}\times A}{100}\text{ rad/sec}$$

$$=5{\cdot}92\times10^2\,\bar{E}\,A\text{ rad/sec}$$

$$2{\cdot}13\times10^6\,\bar{E}\,A\text{ rad/h}$$

If half the infinite volume is removed then the dose-rate at the surface thus formed will be reduced to one half because half of the source of the dose is removed. Hence the dose-rate at the surface is:

$$d_s=2{\cdot}96\times10^2\,\bar{E}\,A\text{ rad/sec}$$

$$=1{\cdot}07\times10^6\,\bar{E}\,A\text{ rad/h}$$

The thickness required to give equilibrium so that the semi-infinite condition is satisfied varies with energy, but about a g/cm² is sufficient for all except the most energetic beta particles.

Such calculations are useful as a guide to the dose-rate

to be expected, but it must be remembered in dealing with pile produced isotopes that other substances may be present even after chemical separation. The quantity may be very small but the specific activity may be high enough to give a significant increase in the dose-rate. It is, therefore, advisable to check theoretical estimates by measurements on the actual material before permitting wide-scale handling under conditions laid down by calculation.

Small neutron sources using the (α, n) reaction such as Ra-Be, Pu-Be or Po-Be may be reckoned to give about one neutron per 1000 alphas. The neutrons from such sources are in the high energy region from about 5 to 10 MeV.

Very large outputs of neutrons can be obtained from accelerators using processes such as deuterons hitting a deuteron target. It should be noted that electrons will pass along the tube in the opposite direction to the positive particles and will give rise to an X-ray source at the end away from the neutron-producing target. In general gamma radiation of some sort should always be looked for in connexion with neutrons.

Measurement of dose

The fundamental method of measuring a dose of X or gamma rays is by the ionization produced in air using a free-air chamber. In this a collimated beam of radiation passes between collector plates in such a way that primary ionization occurs in a volume of air which is defined by the collimation and by the collecting field and not by any wall material. The space around this defined volume must be large enough to allow secondary ionization to be complete and the voltage gradient must be sufficient to ensure collection before any significant recombination can take place. Since such chambers are necessarily cumbersome and require great care in their operation, they are used only as primary standards at special calibrating laboratories such as the National Physical Laboratory[6]. Most other laboratories make use of secondary standards, such as high quality condenser chambers, which have been calibrated against these primary standards.

In these condenser chambers a small volume of air is contained by walls of material which is chosen to have an average atomic number close to that of air, and of thickness approximately equal to the range of the beta particles which are generated by the primary radiation. Too small a thickness will give low readings with higher energy radiation, and too thick a wall will attenuate low energy radiation and again give low readings. It follows that any given chamber will cover a limited energy range and outside that range a chamber with different wall thickness must be used.

Most condenser chambers and the chambers of many electronic instruments are made to give satisfactory results over a range from about 50 keV to 1 MeV. Special types are made for higher energies and in these the outer part of the wall may be of metal such as steel or aluminium, provided there is an inner wall of air-equivalent material thick enough to stop the photo-electrons from the metal.

Condenser chambers with a simple quartz-fibre electroscope built in to measure the charge are made in the size and shape of a fountain pen and these, or the simple chamber with separate measuring instruments, can be used for personnel monitoring devices for X and gamma radiation in circumstances where a fairly large dose is anticipated in a short time.

For general use as a personnel monitor the film badge is most satisfactory. This is a small piece of double coated sensitive X-ray film of the size used for dental radiography and similarly wrapped except that no metal screens are included. Photographic film emulsions have an enhanced response at low energies, peaking at about 50 keV to some 10 or 20 times that at 1 MeV. To even out the response a filter is placed around the wrapped film to attenuate the lower energy radiation; a thickness of 1 mm of tin or cadmium is usual and gives nearly flat response from several MeV down to about 40 keV, below which there is a sharp cut off. The dose-density characteristic of the emulsion is not straight so that it is necessary to do a careful calibration covering the full range of exposures for which any emulsion is intended to be used. Also because there are slight differences in sensitivity from batch to batch a few points on the curve should be repeated for each batch. The calibration is best done using a gamma-ray source such as radium or Co-60 with the films arranged round it on a light frame, and the whole set up in the centre of a room away from walls, benches and floor so as to reduce scattering of the radiation to a minimum. The variation of dose can be achieved either by removing films one by one at different times or by adjusting their distance from the source and giving all the same time of exposure. Development must be carefully controlled and at least one unexposed film, for background level, and one with a known exposure should be included in each lot which is processed.

Where there is handling of beta/gamma active materials in quantities greater than a few tens of millicuries, wrist films should be worn to enable an estimate to be made of the dose to the hands and fingers. The film is worn at the wrist for convenience and, since the dose to the fingers is likely to be higher than that received by the film, it is advisable to make a series of measurements under typical working conditions to determine the ratio between them. Some estimate of the beta-ray dose can be made from the density of the unfiltered part of a film badge but it is difficult to obtain any reasonable accuracy without a knowledge of the energy.

Neutron dose is also very difficult to measure with a personal monitor. The dose of thermal neutrons plus gamma can be taken from the film under a cadmium filter since the blackening due to equal fractions of the permissible dose is approximately equal. Fast neutrons can be estimated by the use of nuclear emulsion plates with counting of the tracks and measurement of their length under a microscope to give numbers and energy of the neutrons. This is very tedious and time-consuming work and it is well to avoid it as much as possible by extra care in ensuring that the radiation conditions are such as to make the likelihood of exposure to more than a fraction of the permissible dose very small.

Protection from external radiation

In many cases the best and cheapest way of reducing the exposure is distance. Since many sources are effectively point sources, the dose-rate falls off with increasing distance according to the inverse square law, so that doubling the distance reduces the dose by a factor of four, and so forth. A very useful and generally practicable example of this is the use of tweezers or tongs for handling beta or gamma emitters. X-ray sets and large gamma sources should be sited in such a way that personnel are kept as far as possible from them when in use. The outside of a building should not be forgotten in this connexion and it is often convenient to put up a light wire fence at a suitable distance so as to prevent unsuspecting persons from approaching too close to such sources.

Another important factor is time. The duration of exposure can be reduced by careful planning of experiments and by dividing the work between several individuals so that each receives only a fraction of the exposure. A different way in which time can be used is by waiting for decay to reduce the dose-rate from things, such as fission products in some cases, which are an unwanted incidental to the work in hand.

The third factor is shielding. This means interposing between the source and the operator or part of his body some material which will attenuate the radiation. In choosing shielding materials it is important to consider whether the shield will give rise to radiation by any kind of reaction with the primary radiation. Thus a small thickness of material will reduce beta radiation from quite intense sources to an acceptable level, but if any but low atomic number elements are used the *Bremsstrahlung* give a hazard. The most suitable substances for beta shields are unloaded plastic such as Perspex. One or two centimetres of such material is usually sufficient.

For X and gamma rays up to 200 or 300 keV, lead is particularly useful because of its high mass-absorption coefficient and can be used as bricks for local shielding or in sheet form to cover walls or make boxes. A three-ply with wood faces can be used which overcomes the tendency to flow when not properly supported. At short distances in the direct beam of an X-ray set thicknesses up to 2 cms may be required, but outside the beam a few mm is usually adequate. Observation windows should be made of lead-bearing glass and attention should be given to securing an adequate overlap at the framing.

At higher energies lead is still useful, particularly where space is important, but it begins to lose its special advantages and at energies of 1 MeV and over shielding becomes largely a matter of the mass of material which is interposed between source and operator. Here concrete and brickwork are useful and economic because they contribute to the constructional strength of the building. Concrete will generally require to be 7-10 times the thickness of lead for the same protection and brickwork some further 60% thicker. In the direct beam of high energy X-ray generators some 3-4 feet of concrete will be required, but in other directions, provided there is suitable collimation such as a lead cylinder round the target, the normal structural walls will often be satisfactory if any window openings are kept six feet from the ground.

In designing shielding for handling high activity sources it is often found inconvenient to shield the top because of access requirements for handling gear, periscopes and the like. In such cases care must be taken to avoid undue scattering of radiation over the top of the face shield on to the operator. The best solution is usually to make a very light roof which causes very little scattering or, if this is not possible, to arrange a labyrinth structure such that there is full shielding between the operator and any surface which can see either the source or a primary scattering surface.

In protection from neutrons much can be done by slowing down since the permissible flux is much greater for the low energies. Light materials, especially those containing hydrogen, are most effective for this but it must be remembered that the resulting thermal neutrons are readily captured and often give rise to penetrating gamma radiation. Water forms a useful shield material especially if soluble compounds of boron are added to it, since boron gives low energy capture gamma rays. For permanent large scale shields, concrete is probably the most generally used material and is sometimes loaded with iron, iron ore or barytes. Cadmium has a high cross section for thermal or near thermal neutrons and fairly thin sheets of the metal can give good shielding against these energies in cases where the area required is small enough to make it economic.

Surveys and area monitoring

Whatever shielding is used, and even where such protection is not considered necessary, careful surveys should be made in the working area to determine the dose-rate which is likely to be experienced under actual working conditions. Small area beams due to imperfect fitting between parts of the shielding are easily overlooked and particular care must be given to all places where these might occur.

These surveys should be made as far as possible before work begins and supplemented by further measurements during the actual operations. Where the same job is done regularly, or similar ones under similar conditions, area monitors should be installed whose readings, after comparison with the survey, will indicate whether satisfactory conditions are being maintained. These area monitors may be fitted with alarms to give warning when a predetermined level is exceeded.

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continued from page 293

matically take over and maintain forced circulation, limit both the maximum and final fuel temperature. However, by careful design of the coolant circuit, it is possible to achieve a sufficient flow of coolant by natural circulation only so that even under this most serious fault condition the fuel cans do not reach melting point. In the Bradwell design the natural circulation at design temperatures is approximately 10 per cent. The auxiliary circulator drives give 20 per cent of design coolant flow, which in addition to affording a good safety margin simplifies start-up procedure.

In gas cooled reactors with large ducts and expansion joints, very great care is taken in the design and the proving of the pressure circuit to ensure that fracture will not occur. However, such a failure must be considered as a possibility. Fortunately should even a main duct fracture and the coolant pressure fall to near atmospheric in a few minutes, it is possible by running the circulators with their auxiliary drives to maintain the fuel temperature only slightly above the design value. With natural circulation only, the temperature rise would be much greater but still below the melting point of the fuel cans.

During shut-down, coolant must continue to circulate through the reactor to remove the heat generated by fission products. Although this is normally done by running the circulators with their auxiliary motors fed from a guaranteed supply, with good natural circulation no serious harm would result from the failure of these circulators or the supply.

In addition to ensuring circulation of coolant through the reactor core, at all times it is important to maintain a supply of water to the boilers in order to remove the heat from the coolant. In the normal operating condition the problem is the same as in conventional boiler practice. Duplicate feed pumps, if possible fed from separate electric supplies, with automatic change-over are used. In nuclear stations temporary loss of boiler feed is not quite so serious as in normal boilers since they have a fairly large water capacity and cannot be burned out by the reactor coolant. Following a reactor trip the water capacity of the boilers would be sufficient to remove the shut-down heat for at least thirty minutes in which time an auxiliary feed pump driven from a guaranteed supply could be put into operation. Even if the steam generated could not be condensed and make-up water was not immediately available the water capacity of the feed system would be adequate for some days.

BOOKS

For the nuclear physicist . . .

Neutron Transport Theory B. Davison, The International Series of Monographs on Physics, 6½ in. by 9½ in. 450 pp. London 1957: Oxford University Press Price 75s.

One of the fundamental problems in nuclear engineering is that of calculating the critical size of a reactor. The elementary approaches usually used are approximations to more accurate methods. The justification for using the approximate methods is that they are usually sufficiently accurate at least for preliminary design studies on reactors. However, an accurate treatment of neutron behaviour is often required and transport theory supplies this. Dr Davison's book is a rigorous mathematical treatment of transport theory and is the most comprehensive published to date.

The book is divided into four parts. The first is introductory, in which the author discusses the physical behaviour of neutrons in contact with matter, and then formulates the laws of neutron migration leading to the two usual equations describing neutron behaviour, namely the transport or Boltzmann equation and the integral equation.

The second, and largest part, covers the solution of these equations when it is assumed that the neutron cross-sections are independent of the energy (the one velocity approximation). Special solutions are discussed, the diffusion approximation is derived, followed by the Serber-Wilson method of solution, and then the very powerful spherical harmonics method is detailed at length. Perturbation, variational, iterative and Monte Carlo methods are also discussed, and finally in this part the subject of anisotropic scattering is treated.

The third part introduces energy dependent cross-section problems and their solution by multigroup theory, polynomial approximations and Feynman's method.

The final part deals with slowing-down problems. The age theory treatment is considered followed by the problem of slowing-down at large distances from the source, first with constant and then variable cross-sections. Finally Holte's method of solution is described.

This is a first rate book for the theoretical physicist concerned with neutron transport problems and one which will surely become a classic. It is a worthy member of the International Series of Monographs on Physics.

James F. Hill

. . . for the interested layman

Radioisotopes—a New Tool for Industry S. Jefferson, 110 + ix pp and 44 figs. London 1957: George Newnes Ltd. Price 17s 6d

This is a book for the business man and the interested layman rather than the technician or the engineer. It aims to give them an insight into the way the radioisotopes are providing a new tool to aid industry.

The greater part of the book is concerned with a consideration of some of the more important applications of isotopes in industry, and amongst the examples discussed are radioactive tracers or markers, the detection of leaks, checking the thoroughness of mixing processes, the measurement of thickness of sheet materials and pipes, the measurement of level and density, the use of isotopes for radiography and autoradiography, and the elimination of static charge. The second part of the book gives a discussion of the fundamentals of radioactivity, and considers in an elementary manner such subjects as atomic structure, nuclear fission and nuclear reactors, the transmission and detection of radiation, and health protection.

To a large extent technical language is avoided with the result that the book should be easily understood by all who wish to obtain a quick appreciation of the subject without too much hard work.

PUBLICATIONS

Talbot Stead Tube Co Ltd, Green Lane, Walsall, one of the Tube Investments companies, have published a useful pocket book: *Data on Steel Tubes and Bars.* Running to 279 pages this is based on the relevant British Standard specifications and forms a very convenient reference.

Nash & Thompson Ltd, Oakcroft Rd, Chessington, Surrey, have introduced a new Resistance Capacitance comparison Bridge—the first of a new range of compact, low-priced electrical test instruments. It is described in a leaflet.

Atkins, Robertson & Whiteford Ltd, Industrial Estate, Thornliebank, Glasgow, have issued a leaflet on their new model 6001 Universal Electronic Batching Counter. It can count up to 6000 a minute, preselect from 1 to 1000 and record up to one million counts.

Metropolitan-Vickers Gazette April 1957 contains an article on the water-cooled alternator by J. Tudge.

Short Brothers & Harland Ltd, 208a Regent St, London, W1, have started a new periodical—*Computer News.* It contains articles on the company's computing and simulation equipment.

Hopkin & Williams Ltd, Freshwater Rd, Chadwell Heath, Essex, have issued a short catalogue—*MFC Materials for Chromatography.*

Bailey Meters & Controls Ltd, 153 Moorgate, London, EC2, have issued leaflets on two new products—The Bailey Strip Chart temperature recorder and the Bailey Electrical Control Station.

Edwards High Vacuum Ltd, Manor Royal, Crawley, Sussex, have issued a revised version of catalogue E177 describing their ½lb vacuum furnace. The firm say since it was introduced this furnace has been used on a wide scale both here and abroad.

Lafarge Aluminous Cement Co Ltd, 73 Brook St, London, W1, have issued a completely rewritten booklet on refractory concrete giving full information on materials for making, mixing and placing.

The Simon Magazine, April 1957, published by the Simon Engineering Group refers to the GEC Simon-Carves nuclear power station for the South of Scotland Electricity Board and mentions that the Group's share in the contract is nearly half the total.

Quasi-Arc Welding News, May 1957, describes how the Dounreay Fast Reactor sphere was welded. Quasi-Arc Ltd, Bilston, Staffs.

EMI Sales & Service Ltd, Hayes, Middlesex, have issued a box containing samples of their recording tapes—*Emitape* on pvc base and *Emifilm* on photographic film base.

The CAC Magazine Spring 1951, from Cape Asbestos Co Ltd, 114-116 Park St, London, W1, contains what must be one of the clearest expositions of the European Common Market and Free Trade Area ever published—by Cape's Commercial Manager (Overseas) Malcolm Reid.

Mitchell-AMF reactor for Bavaria

The site for the Mitchell Engineering/AMF Atomic closed-cycle boiling water reactor ordered by Reinisch Westfalisches Elektrizitätswerk AG has now been announced. Early reports suggested that it would be in the Cologne-Düsseldorf area, but Mitchell have now stated that the site is near Dettingen, Bavaria. Mitchell were awarded the contract in May against eight other bidders (*Worldview*, May), and construction is due to begin in July. AMF Atomics Inc, New York, will supply the core assembly, control gear and instrumentation, while Mitchell will be responsible for the reactor pressure vessel design, primary and secondary heat exchangers, pipe work and containment. Civil engineering, building and turbine power plant will be German and the United States is to supply enriched uranium.

Racal present for inventor

The high Commissioner for South Africa, Dr J. E. Holloway, was amongst the guests at the reception on June 11 in the Savoy Hotel, London, at which Mr T. L. Wadley was presented with a gold cigarette case by Racal Engineering Ltd. Making the presentation, Racal chairman, R. F. Brown, said Mr Wadley had produced two revolutionary ideas: the Racal RA 17 communications receiver which, he said, set new standards in frequency stability and resetting accuracy, and the *Tellurometer* — a microwave radar with an accuracy of 6 or 7 inches in 35 miles. Mr Brown said his firm had already sold over 700 RA 17 sets and would top 1000 this month.

Replying, Mr Wadley—who has now returned to Johannesburg—said inventing these sets was only half the job: just as much credit was due to Racal who had productionized and marketed them.

Hobson instal computer

H. M. Hobson Ltd of Wolverhampton, who have long been associated with developments in aircraft ancillaries, have recently purchased an Elliott G-PAC analogue computer for advanced studies of the dynamic performance of fuel systems and servo control units. It is a standard Elliott two-cabinet machine, equipped with 32 computing amplifiers and, since many of the problems encountered in this field of investigation are non-linear, it also uses some of the latest non-linear units developed by the manufacturers. These include an electronic delay unit with a range 0·1 to 0·2 in steps of 0·01, an arbitrary function generator, and two high-performance servomultiplier units of a new design.

In addition H. M. Hobson are actively engaged in the nuclear engineering field, and the G-PAC will be used for solving problems in this work.

Big pump order

An order worth £430,000 for 176 special glandless circulator pumps for hot water circulation in heat exchangers has been received by Hayward Tyler & Co Ltd. Similar to the 36 units already installed at Calder Hall and on order for Dounreay and Chapelcross, these will be for Bradwell (48 pumps), Berkeley and Hunterston (64 pumps each), and will be delivered over the next two or three years. Chosen for their leak-proof quality, pumps are totally enclosed and designed to run for long periods without maintenance.

Mr John Raymond, MIEE, Hayward Tyler chairman

Hayward Tyler have recently grouped with Messrs Platt Bros & Co (Holdings) Ltd, who purchased a majority financial interest but left the administrative responsibility to Hayward Tyler. Link will enable the companies to provide additional facilities for research and production in the nuclear power industry.

Export film shown

Britain's first coloured documentary film on the peaceful uses of atomic energy had its London premiere during the last week in May. This is the first of a series called 'British Atomic News' which will feature British equipment used in the nuclear industry. They will be shown to prospective buyers abroad, with commentary in the appropriate language.

The scheme was launched last year by Mr B. Charles-Dean managing director of Hartley-Ward Films Ltd, following long talks with the UKAEA and the Board of Trade, and he has produced and directed the first film. The idea was born after the Geneva Conference when Mr Charles-Dean realized that 'you cannot sell atomic goods like a brush salesman going from door to door. Atoms and modesty are a paradox'. Series will include films about radioactive isotopes and automation, and, to assist problems of the technical labour shortage, a training film programme is planned.

British Oxygen expand

Due to the rapid expansion of industries in the North East, British Oxygen Gases Ltd are building a new factory at Grangetown, Middlesbrough, at an estimated cost of £M1¼. The new plant, built by British Oxygen Engineering Ltd, will produce compressed and liquid oxygen, and liquid and tonnage nitrogen, which will be fed, after purification, by pipeline to the ICI factory at Wilton. A plant capable of producing 200 tons of gaseous oxygen per day will also come into operation at a later date, and other industrial gases manufactured by the company will also be distributed from Grangetown.

The activities of the British Oxygen factory at Billingham have been transferred to the new site, which comprises 20 acres. The Billingham works, which has been in operation since 1923, was responsible for about one third of the total sales of compressed oxygen in the Company's North East district.

A number of senior personnel from the company's factory at Chester-le-Street have been transferred to the new building, and additional local labour has been recruited.

'Integron' tubing for new stations

A revised version of a booklet from ICI Metals Division claims that *Integron* high-fin and low-fin tubing can be used as extended surface boiler tubes and as fuel cans in reactors. *Integron* is manufactured from one piece of metal, the fins being extruded from a portion of the tube wall by rotary cold forming. A thick-walled tube is fitted over a plug and fed into three forming rolls spaced at 120°, consisting of a series of annular formers of gradually increasing diameter and changing profile. The first two formers make a small groove which

is deepened as the tube progresses through the rolls. At the same time the thick stubby fin, which is trapped between the first two formers, is gradually squeezed out. The plug in the bore of the tube ensures complete dimensional control of this part of the tube.

Integron tubes are made in three forms—High-fin, Bi-metal and Low-fin. High-fin is normally made in copper, copper alloy, aluminium or mild steel, and the standard range is made in bore sizes from $\frac{3}{16}$ in. to 1 in. with 5, 7 or 9 fins per inch. Bi-metal also has the inherent characteristics of integral fin construction, and differs from High-fin only in that it has a liner or inner tube to suit particular corrosive conditions. Low-fin tubes are an important advance because they can be used in conventional shell and tube heat exchangers.

Full details are given in the booklet *Integron High-fin and Low-fin tubing*, obtainable from ICI Metals Division Headquarters, PO Box 216, Birmingham, 6.

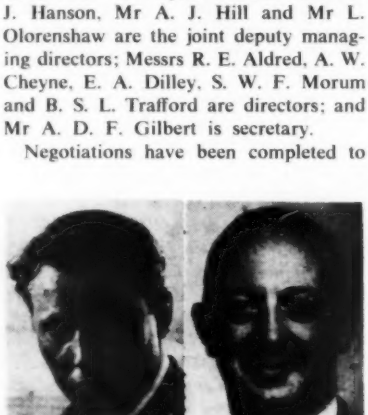
Low-fin, High-fin and Bi-metal 'Integron' tubes, with various end finishes

Taylor Woodrow reorganization

New directors and the formation of new companies have been announced by the Taylor Woodrow Group. Mr Frank Taylor, chairman and founder of the firm, has relinquished the chairmanship of Taylor Woodrow Construction Ltd to devote more time to the overall Group policy in the United Kingdom and the five Continents. Mr A. J. Hill, managing director of the Construction company becomes chairman as well. Mr T. Freakley and Mr T. Reeves (see *Names in the News*) are appointed joint deputy managing directors, and Mr D. A. J. Ballinger, Mr. B. F. Higgs and Mr H. R. MacDonald become directors. Mr Ballinger was agent, then contracts manager, in charge of Calder Hall A and B contracts, and is now in charge of Taylor Woodrow's atomic power department.

A new company has been formed in Taylor Woodrow (Overseas) Ltd, a reorganization of Taylor Woodrow (Middle East) Ltd. Mr Taylor is chairman, Mr J. Hanson, Mr A. J. Hill and Mr L. Olorenshaw are the joint deputy managing directors; Messrs R. E. Aldred, A. W. Cheyne, E. A. Dilley, S. W. F. Morum and B. S. L. Trafford are directors; and Mr A. D. F. Gilbert is secretary.

Negotiations have been completed to



Mr D. A. J. Ballinger (left) and Mr A. J. Hill

purchase control in the British Overseas Engineering Construction Corporation Limited, engaged in the export of machinery and plant. Mr E. J. Woolf, a director of Taylor Woodrow Limited has been appointed chairman of BOECC, and Mr P. L. Baker, of Taylor Woodrow, has been appointed a director.

Nuclear Metals for TI

Remarkable progress in the development of reactor-grade metals is reported in a recent publication by TI Nuclear Engineering Ltd. Metals which were, until recently, used only as alloying constituents are now available in the pure state in commercial quantities. Niobium, for example, is being made in $\frac{1}{16}$in. dia tube with walls 0·004in. thick, and also in 2in. tube. These are being supplied to the AEA for The Dounreay Fast Reactor fuel element sheaths. Vanadium, too, is being supplied as tube for the same purpose. Beryllium tubing in 1in. and 2$\frac{1}{2}$in. dia is also available and research is continuing on methods of improving ductility and on joining. Zirconium and Zircaloy tubing in commercial grades are available now and reactor-grade material is expected to be available in commercial quantities before the end of the year. Tantalum and molybdenum tubes are also available, but supplies are at present limited by material shortages.

Tube Investments Steel Tube Division embraces 12 subsidiary companies. Applications for atomic energy include: extended surface tubes, tubing with 0·003in. walls, control rods, charge tubes, absorber rods, fuel element supports, neutron starter tubes etc.

Much amusement must have been caused recently by a half-page advertisement that recently appeared in the *Financial Times* for Accles & Pollock Ltd—a TI company. Entitled 'the tubular an-atom-y of an atomic power station', it depicted how a gas-cooled graphite-moderated reactor could (by a wide stretch of imagination) be considered as mostly a collection of A & P tubing in various forms. It also showed something of home life at 'Entre Nous'—the home of those legendary twins Mr Accles and Mr Pollock—and how it benefits from the blessings of atomic energy. A reproduction of the advertisement appears in this issue of NUCLEAR POWER.

Vokes show Auto-roll

A private exhibition showing the whole range of products of the Vokes group of companies, seventh in the series, was held recently in the Kensington Palace hotel. Many new products were shown for the first time by the parent company, Vokes Ltd, among them the *Auto-roll*, an automatic screen type air filter for air-conditioning and ventilating systems, which has its medium disposed between two rollers so that dirty cloth is replaced by a few turns of the lower roller. A similar filter is the SC type, another automatic rotating screen but of wire mesh panels with an in-built oil bath, offering reasonably high efficiency under heavy dust concentrations with no servicing requirement.

A new range of large capacity oil bath air intake filters, designed to supplement their existing range were also shown, together with paper element air intake filters using plastic or metal cowls for a wide variety of installations.

The remainder of the Vokes Ltd exhibit consisted of their standard range, including high efficiency filters for control of radioactive dust in nuclear power and research stations.

Kent's part in HIFAR

More details about the instrumentation for the High-Flux Australian Reactor (*Companies*, May) are now available. The main contractors, Head Wrightson Processes Ltd, placed the order for the actual control panel and all the physical instruments with George Kent Ltd, and recorders for the nuclear instrumentation were ordered from Kent by Ekco Electronics Ltd. When work on the panel was completed at Kent's, it was sent to Ekco, who cooperated with Kent in this work and completed the panel by adding their own nuclear and health instrumentation.

In Australia, Kent engineers will assist in the erection, installation and commissioning of the equipment on site.

Some personnel will be drawn from the Kent associate company in Sydney, Davies-Kent Pty Ltd.

Among the equipment supplied by Kent for the reactor were *Multilec* instruments for flux power, fission products, gamma radiation, fuel element, water and heavy water temperatures, etc. and instruments from the *Commander* range for measurement of coolant and heavy water flow, heavy water level, and reactor helium pressure.

Kent have received a similar contract for almost identical work on PLUTO (Harwell) and DMTR (Dounreay).

Joint undertaking

An agreement has been made recently between Keith Blackman Ltd and Prat-Daniel (Stanmore) Ltd by which both companies will be able to offer complete draught equipment for power station and industrial work. Keith Blackman are well known as manufacturers of *Tornado* fans, and Prat-Daniel multitubular dust collectors are also in extensive use in power stations.

Another agreement with the Aerotec Corporation of America, has resulted in the introduction of electrostatic precipitators to the range of both companies. Under this arrangement both Keith Blackman and Prat-Daniel are able to offer complete mechanical draught and grit arrestor equipment to boiler makers and users.

Selling abroad

Publicity overseas for British products is available through the Government's Central Office of Information. In nearly every country there is a UK information officer whose job includes providing the Press of his territory, including both general and trade papers, radio and television stations, with news and information about Great Britain. Information is provided by the COI, which is advised by the Board of Trade on the trade and industrial side. The extent to which the demand for British products can be enhanced depends on the amount and quality of material supplied by individual firms. Many firms are taking advantage of these facilities, but more could profitably do so; a great part of the service involves the manufacturer in no expense at all.

Main source of publicity for British atomic energy developments are feature articles, and papers by Sir John Cockcroft and Dr Seligman have been issued by the COI. News stories about developments, including those by private firms, are cabled abroad as they occur. In addition to booklets, periodicals etc, display material, films and exhibitions are also used for publicity. Films by the AEA, the COI, and commercial interests have been distributed overseas through the official information services.

LLD for Sir George Nelson

Honorary degree of Doctor of Laws was conferred on Sir George Nelson, Chairman of English Electric, at Manchester University last month. Trained at the City and Guilds Technical College, Sir George took his diploma before he was 18, and is now a fellow of the College. He won a Brush post-graduate studentship, becoming a premium pupil of the Brush Electrical Engineering Company at Loughborough, and at 22 was appointed chief outside engineer. Later he joined the British Westinghouse Company, now Metropolitan-Vickers Electrical Company Ltd, and by 1920, when only 33, he established and became manager, of their Sheffield works. He joined

Sir George Nelson, EE Chairman

English Electric in 1930 as managing director, becoming Chairman three years later.

Sir George was knighted in 1943 in recognition of his public work, and in the 1956 Birthday Honours, was created Baronet. He is a past-president of the IEE and is now president of the IMechE.

New vacuum standards

Early research in atomic energy was dependent on high vacuum techniques, and today many aspects of the field would be impossible without vacuum equipment. This was stated by the chairman of Edwards High Vacuum Ltd, the Rt Hon Lord Wilton of Selmeston, in his recent review of 1956, who added that as a result the company had developed its entire range to standards comparable to those required in atomic energy. He pointed out that geiger counters rely on vacuum techniques for their operation; reactor fuels are produced by high vacuum metallurgy; the 'new' metals—uranium, titanium, zirconium, molybdenum, tungsten—are processed in vacuum. Also television tubes, radio valves and many electronic devices depend on high vacuum for successful working. Lord Wilton said that Edwards leak-testing equipment, built primarily for the stringent needs of atomic energy, is now increasingly used in commerce for testing cans, drums, tanks etc.

Edwards and three other companies have recently cooperated in making the coloured documentary film British Atomic News (see page 299).

New Laing venture

John Laing and Son Ltd and the H. K. Ferguson Company of Great Britain Ltd have formed a separate association in the name of Laing-Ferguson to provide a complete and comprehensive construction service to the chemical, processing, and manufacturing industries. The firms believe the integration of all aspects of construction under a single controlling responsibility has already proved a means of achieving a significant and much needed speed up of completion schedules in this class of work. John Laing projects in recent years include the twin atomic reactors at Windscale, heavy foundations for the cold reduction mill at Abbey Works, Margam, and extensive construction work for Britain's oil refining and petrochemical industries. In Africa the company has played a leading part in the construction work of gold mining and uranium plants in the Orange Free State and in the Transvaal.

The H. K. Ferguson Company of Great Britain is a subsidiary of the American company of the same name. The British company is already established in this country and has worked for such companies as Thomas Hedley and ICI. They collaborated with John Laing on the new foundry for the Ford Motor Company at Dagenham.

In brief

G. & J. WEIR LTD announce that they have acquired a controlling interest in a well-known Canadian firm of manufacturers' representatives and engineers, Peacock Bros Ltd of Ville La Salle, PQ. The firm has represented Weir and Drysdale, as well as other important British and American firms.

THE PULSOMETER ENGINEERING CO LTD have acquired the whole of the issued share capital of Skyhi Ltd of Isleworth, Middlesex, manufacturers of hydraulic pumps, jacks, lifts and agricultural loaders. Mr W. T. S. Weir and Mr A. H. Stead will continue as joint managing directors and Mr F. B. Duncan and Mr J. S. Woodrow have joined the board.

INSTITUTIONS

£100 per kilowatt—Duckworth

The most obvious disadvantage of nuclear power stations at present is their high capital cost. In carrying out a large nuclear power programme an immense capital outlay is involved even though ultimate generation costs may not be materially increased. Immediate efforts are, therefore, being made by all designers to reduce capital costs per kilowatt sent out. This was stated at Eastbourne last month by Mr J. C. Duckworth, Deputy Chief Engineer (Nuclear Power) of the CEA, discussing future trends of *Nuclear energy in Great Britain* in a paper presented to the British Electrical Power Convention.

The present type of gas cooled thermal reactor, using natural uranium and solid rod fuel elements with magnesium alloy canning, had certainly not yet reached its zenith with the Bradwell, Berkeley and Hunterston designs, great advance though these were on Calder Hall. It seemed probable that, with improvements in engineering technique only, the cost of a typical two-reactor station might well fall soon to a figure only slightly in excess of £100 per kilowatt sent out, including the allowance for access road construction, electricity and water supplies, engineering charges, etc. At this capital cost, the overall generation costs of the nuclear station would be more directly competitive with that of modern conventional stations.

The general tendency in all the systems mentioned was for the degree of enrichment of the fuel to increase, coupled with a decrease in core size of the reactor. This tended to lead to a steady reduction in capital cost per kilowatt, but also to difficult engineering problems in removing large quantities of heat from small volumes, which in most cases necessitated the use of liquid metal coolants.

It was not so easy to predict the trend in fuel costs. At first sight, it might appear that fuel costs would tend to increase, since expensive enriched materials would be used. However, at the same time much greater burn-ups would become possible, and which of these effects would predominate it was difficult to say.

There seemed no doubt, however, that total generation costs from nuclear power stations would continue to fall rapidly for a number of years. Nuclear power stations must be competitive at lower load factors than 75 per cent. if much more than about 9000 MW was to be installed by 1970, and it was confidently expected that this would be the case. It might be, especially if the lower capital cost stations had higher fuel costs, that a whole range of different type nuclear power stations was continually under construction, different types being most economic for different load factors. It was clear that a very great reduction in capital cost per kilowatt would be necessary before nuclear stations could compete with conventional stations at very low load factors, so that it was far from certain that only nuclear stations would be built after the late 1960's; it might be that it would be economically desirable to build conventional stations for peak load operation for many decades yet to come.

In a paper on the economic aspects of high voltage transmission, Mr F. J. Lane, Deputy Chief Engineer (Transmission), and Mr W. Casson, Transmission Design Engineer, also of the CEA, said there is little reason to fear that the Super Grid will be unsuitable in any important respect for use in conjunction with large amounts of nuclear power even though it was designed in the expectation that home-produced coal would be almost the sole source of fuel for electricity generation in Great Britain for many years.

Harwell course for biologists

A five day course on autoradiographic techniques, of particular interest to biologists, will be held at the Isotope School, Harwell, from July 22-26. Lectures and demonstrations will be given covering the basic principles of autoradiography and the interpretation of results. Demonstrations on stripping film, and coating and squashing techniques will be followed by practical work on squash preparations for autoradiography and on the processing and staining of autoradiographs using normal and phase contrast microscopes. The course has been arranged in cooperation with Dr S. R. Pelck of King's College, London, who will give most of the lectures and demonstrations. Application forms for the limited number of places available on the course should be sent to the Isotope School as soon as possible. Accommodation can be arranged locally by the School on request.

Cockcroft at SIMA's 41st

The annual luncheon of the Scientific Instrument Manufacturers' Association for 1957, the 41st year of the Association, is to be held at the Savoy Hotel, London, on July 5.

The chief speaker will be the Rt Hon R. A. Butler, Home Secretary and Lord Privy Seal, who will be presented with the first copy of the Association's newly published handbook *British Nucleonic Instruments 1957*. Sir John Maud, Permanent Secretary of the Ministry of Power will also be speaking. Other eminent guests will include the Rt Hon Ernest Marples, the Postmaster-General, Sir John Cockcroft, and Sir Graham Hayman, President of the FBI. Many other guests will be present representing the Government, allied industries, other associations and learned societies, and the general and technical press.

This occasion is for the instrument industry, now so active in electronics and nucleonics, to entertain its friends and colleagues and for its achievements and aspirations to be made more widely known. SIMA represents over one hundred and fifty British manufacturers of instruments, electronics and allied equipment for all classes of scientific and industrial endeavour. Originally based on a small group of optical firms which are still today very active, its largest membership is now of electronic instrument firms, many of which are to the forefront in the rapidly growing and vital fields of nucleonics and the peaceful uses of nuclear energy.

The President of the Association for 1956-7, Mr G. A. Whipple, Chairman and Managing Director of Hilger & Watts Ltd, will preside at the luncheon.

Nuclear course at Nottingham

A short course on nuclear engineering for engineers with little or no previous knowledge of the subject will be held at Nottingham University from Monday, September 16 to Friday, September 20. No formal academic qualifications are required, but the lectures have been designed to degree or Higher National standard. The course will include a series of five lectures on *Nuclear physics and reactor principles* by S. C. Curran, and other titles are: *Heat removal from nuclear reactors* by Prof W. Murgatroyd, *The metallurgy of reactor fuels* by Dr G. W. Greenwood, *Health physics and design safety* by B. S. Smith, *Reactor control* by J. Walker, *Instrumentation for nuclear reactors* by Dr D. Taylor, Instrumentation Editor of NUCLEAR POWER, *Nuclear reactor fuel cycles* by F. W. Fenning, *Chemical processing and fuel production* by N. L. Franklin and *Liquid metal reactors* by S. B. Hosegood.

Application should be made as early as possible to the Hon Sec, Nuclear Engineering Course, Depts of Civil and Mechanical Engineering, University of Nottingham, University Park, Nottingham.

Scaling-up mixer-settlers

Scaling-up of packed columns with any degree of accuracy is difficult and requires considerable effort, although recent work has led to a greater understanding of the problem. But scaling-up of mixer-settlers of the Windscale design has been found by the AEA to be comparatively simple and satisfactory techniques are available which eliminate the need for pilot plant trials. This was stated by Mr B. F. Warner in his paper *The scaling-up of solvent extraction processes for irradiated nuclear fuels,* presented at the York symposium on *The scaling-up of chemical plant and processes* in London last month. The symposium was sponsored by Het Koninklijk Instituut van Ingenieurs, De Koninklijke Nederlandse Chemische Vereniging, the Society of Chemical Industry and the Institution of Chemical Engineers. Mr Warner added that using Windscale type mixer-settlers, it is possible to scale-up from contractors having a throughput of a few litres per hour to ones capable of handling a cubic metre or more per hour. They also have the advantage that the volume of shielding required for radioactive plant is less than that of a packed column and considerable economies in plant design can be made.

NAMES IN THE NEWS

Mr H. B. Topham has been appointed a director of the Anglo Great Lakes Corporation Ltd, the company which was formed by four member companies of the Nuclear Power Plant Co Ltd in conjunction with the Great Lakes Carbon Corporation of New York to produce nuclear graphite in a new Tyneside factory.

Remington Rand Ltd have appointed **Mr Eric Segar** to the post of area sales supervisor (supplies division) for the entire London Region.

The Power-Gas Corporation have appointed **Major W. R. Brown,** DSO, as their chairman and managing director in succession to the late Dr N. E. Rambush whose death occurred in May of this year. Major Brown was first elected to the board of directors in 1942.

Murex Welding Processes Ltd have recently appointed **Mr J. H. Gameson** as assistant to the publicity manager.

Mr H. A. Lewis has been appointed managing director of EMI Sales & Service Ltd in succession to the late Mr E. J. Emery.

Mr Wallace Fairweather has been appointed general sales manager of Clyde Tube Forgings Ltd and Shaw-Petrie Ltd.

Mr Barrell, generator engineer (construction) in the Yorkshire Division of the CEA has been appointed generation construction engineer at Headquarters.

Mr A. S. Dodd has been appointed a director of John Thompson Water Tube Boilers Ltd and London manager of John Thompson Ltd. In the latter post he succeeds **Mr C. J. Howard** who was recently appointed managing director of John Thompson Water Tube Boilers.

The Lead Development Association announce the appointment of **Mr David W. Payn** as general manager and secretary.

Following the recent reorganization of the Taylor Woodrow group of companies **Mr T. Reeves** has been appointed one of two deputy managing directors of Taylor Woodrow Construction Ltd.

Mr L. F. Miller, principal assistant contracts officer, CEA, has been appointed deputy chief contracts officer at Headquarters.

Mr Hendrik F. van der Laan has been elected to the newly created post of president of Vitro Rare Metals Co, a division of Vitro Corporation of America.

New technical secretary of the Radio and Electronic Component Manufacturers Federation will be **Mr Leonard Bennett.**

Mr P. J. H. Coates has been appointed director and general manager of Veritys Ltd. Mr Coates, who is 43, has had an intensive engineering training and held posts with C. A. Parsons and Co and Merz and McLellan, particularly in the field of electrical engineering.

Mr William E. Jenkins has been appointed to the Board of the APV Company.

The CEA have appointed **Mr E. Forth** generation operation engineer, Headquarters. Mr Forth was formerly generation engineer (operation) for the north eastern division of the Authority.

Mr John Montgomery has joined the board of Shaw-Petrie Ltd. Mr Montgomery is also on the board of Clyde Tube Forgings Ltd.

At John Thompson Ltd, Belfast, **Mr James Boyd** has been appointed area manager, to represent all the John Thompson companies in Northern Ireland and Eire. Mr Boyd was previously assistant manager at the company's Glasgow office.

Mr J. E. Clark, who joined the staff of British Oxygen Wimpey Ltd when it was formed last December, has now been appointed deputy manager of the Midlands District of British Oxygen Gases Ltd.

MAJOR W. R. BROWN

MR H. B. TOPHAM

MR T. REEVES

MR J. BOYD

MR A. S. DODD

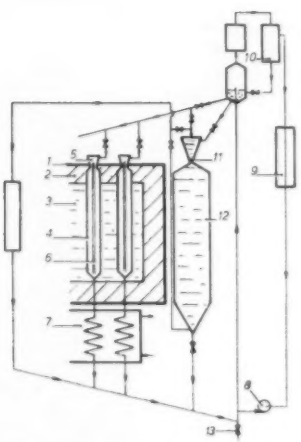
PATENTS

Slurry reactor

773,343 Nuclear reactor and reactor tube therefor. Stichting voor Fundementeel Onderzoek der Materi. Appn: March 8, 1954 (in Netherlands). Pubd: April 24, 1957

The reactor comprises a moderator surrounding a multiplicity of fuel passages through which a suspension of fissionable material in a carrier liquid, such as common or heavy water, is circulated. Criticality may be reached, using natural or only slightly enriched uranium, providing that neutron absorbing materials are not used in the reactor construction and that a high concentration of fuel is maintained. The first condition can be satisfied quite easily, and the invention aims to satisfy the second.

The nuclear fuel descends through the reactor as a concentrated suspension and



773,434 SLURRY REACTOR

1 Pressure resistant jacket
2 Neutron reflector
3 Chamber for moderator
4 Reactor tube
5 Hydrocyclone thickener
6 Overflow pipe
7 Heat exchanger
8 Pump
9 Purification plant
10 Condenser
11 Hydrocyclone thickener
12 Storage tank
13 Safety valve

subsequently a further quantity of liquid is added to dilute the suspension, allowing it to be transported upwards to a point where the concentrated suspension required in the reactor is reformed in a hydrocyclone thickener. The concentrated suspension discharging from the hydrocyclone descends through the reactor and the liquid separated from it, constituting the so-called 'overflow' fraction, is conducted outside the reactor. It then rejoins the suspension which is pumped upwards in a diluted condition by means of an inert gas. The suspension passes through a heat exchanger to a vessel where the gas is separated from it and returned to the pump via a condenser and a purification plant. If the circulating suspension contains too much solid matter, part of it may be led to another hydrocyclone thickener to be concentrated, the thickened suspension subsequently settling in the storage tank.

It is possible to vary the flow velocities in different tubes by employing different hydrocyclones, thus ensuring that the temperature of the suspension leaving each pipe is optimum. The conduits and apparatus outside the pressure jacket must be pressure-tight. The whole system may be drained if necessary through the safety valve.

Pb-Bi alloy in fuel cans

773,021 Improvements in or relating to nuclear reactor elements. Brown Boveri & Co Ltd. Appn: Aug 21, 1954 (in Switzerland). Pubd: April 17, 1957

Under the influence of the high temperatures produced in reactor cores, canned fuel elements tend to change their shape and the sheaths cease to fit closely. This is detrimental to heat transfer and may also cause oxidation of the fissionable material. The invention aims to overcome this by providing an intermediate material to fill the sheath which is liquid at the operating temperature of the reactor. Suitable material should have a low neutron cross section, should not react with the fissionable material or with the sheath, or be attacked by fission products. A suitable medium is an alloy composed of 44.5% lead and 55.5% bismuth by weight, its melting point being 125°C.

Canning uranium rods

773,771 Improvements in or relating to the Metal Sheathing of Solid Bodies. United Kingdom Atomic Energy Authority. Appn: March 1, 1946. Pubd: May 1, 1957

The use of circumferential welds for closing fuel element cans introduces considerable risk of leakage, which this method aims to eliminate.

In the particular case described, a cylindrical uranium rod, plane at both ends, and having a finely machined surface, is inserted in a seamless aluminium can with a wall thickness about 0·030in. and length greater than the rod by about half the rod diameter. The can is cylindrical, fits loosely over the rod and has one end closed. After insertion of the rod the can is cold drawn to fit closely. An aluminium rivet with a disc head of diameter similar to that of the rod and an open-ended, hollow shank, is inserted in the open end of the can with the head against the rod. The end of the can is spun over the rivet head, its edge trimmed with a cutting tool and finally pressed flat against the outer face of the rivet, with its edge closely encircling the rivet shank. The shank is then spread over the unturned edge of the can to complete the joint. To ensure a sealed fluid-tight joint, the overlapping surfaces of the spread part of the rivet and the can may be spot welded together.

Hex process for HAR

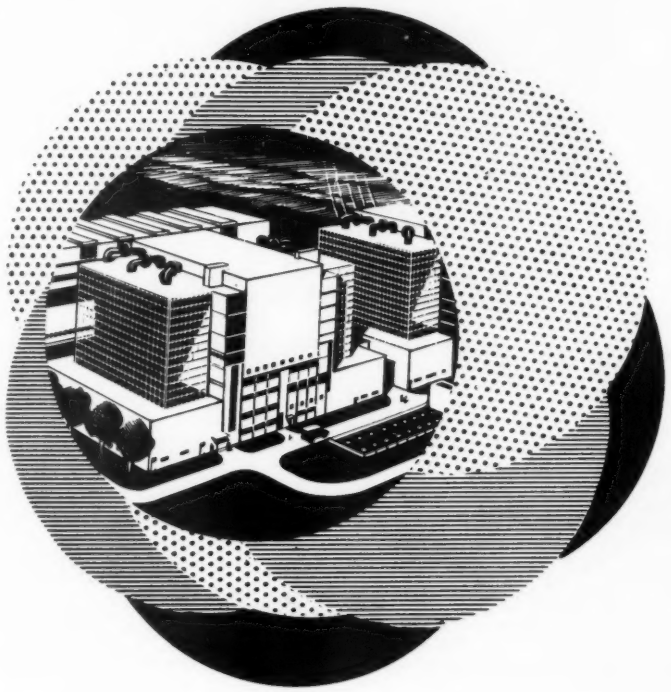
772,617 Improvements in or relating to chemical treatment of plutonium hexafluoride and uranium hexafluoride. United Kingdom Atomic Energy Authority. Appn: July 12, 1954. Pubd: April 17, 1957

Volatile plutonium hexafluoride has a relatively high vapour pressure, is highly toxic and radioactive and must be handled under protective conditions. Any treatment process employed should therefore be simple with the minimum number of stages.

This method is based on the fact that if plutonium or uranium hexafluoride is passed into strong sulphuric acid, a sulphate of the metal is deposited as small crystals. Fluorine is first passed through 98% sulphuric acid contained in a nickel vessel until the gas ceases to be absorbed. Plutonium hexafluoride is then introduced until approximately half the amount needed to react with all the acid has been passed into the vessel. Small plutonium sulphate crystals are deposited, believed to contain plutonium in the tetravalent state. After the passage of the vapour, the contents of the reaction vessel are withdrawn. The sulphuric acid with some plutonium sulphate in solution is separated from the crystals and returned to the vessel with further 98% acid, for treatment of more hexafluoride. The crystals may be worked up to any desired plutonium compound.

Uranium hexafluoride may be treated similarly to give uranyl sulphate crystals. This process may be usefully employed for a homogeneous reactor, having uranyl sulphate solution as the core and a thorium oxide blanket.

These abstracts are made from British Patent Specifications with the permission of the Controller of Her Majesty's Stationery Office. Complete specifications may be obtained from the Patent Office (Sales Branch), 25 Southampton St, London, WC2, 3s. a copy (inc. postage, inland & abroad)



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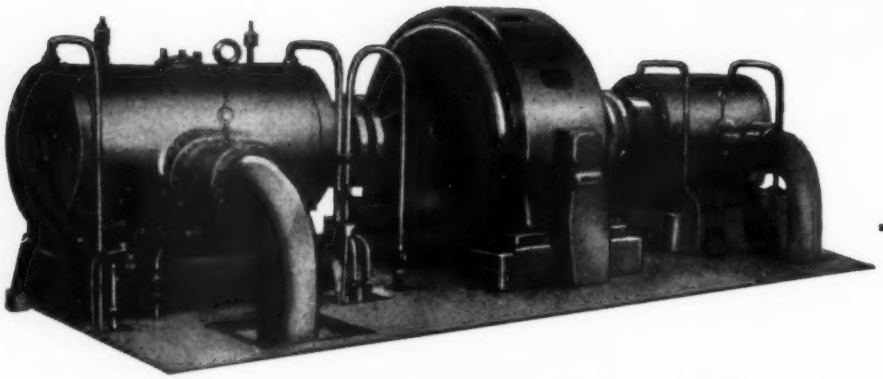

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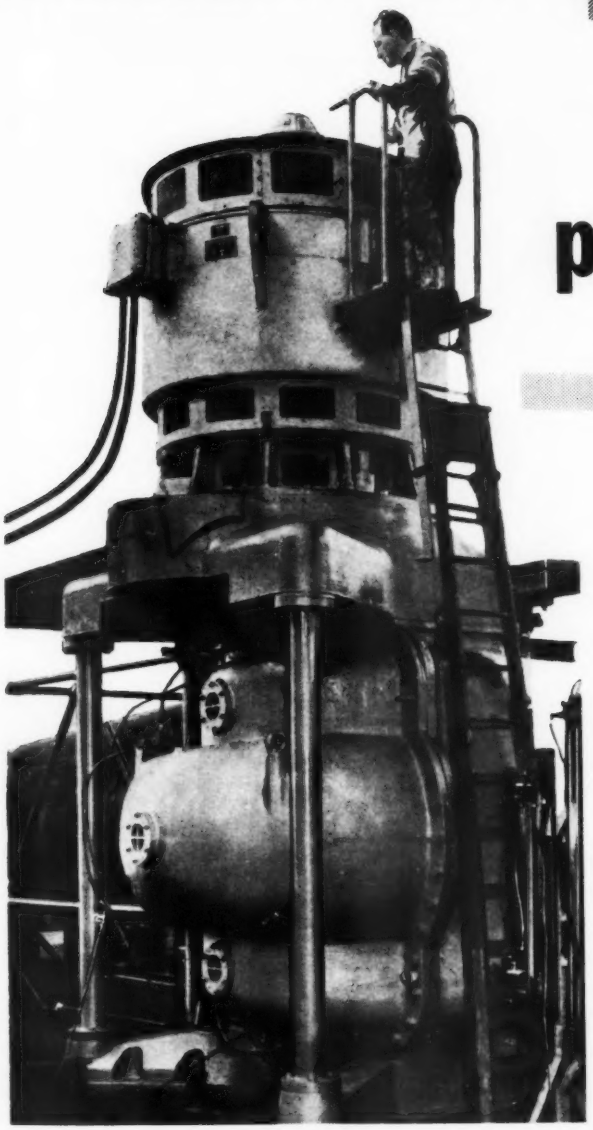

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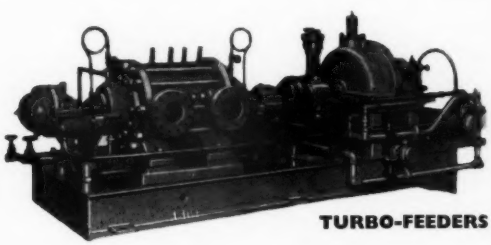

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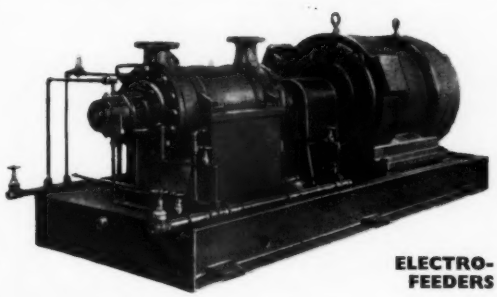

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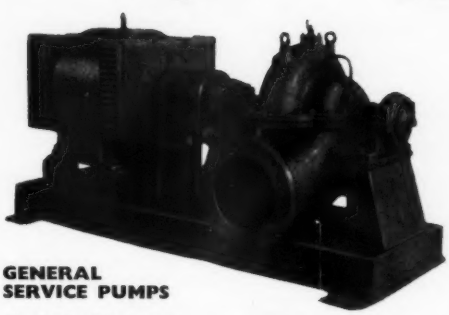

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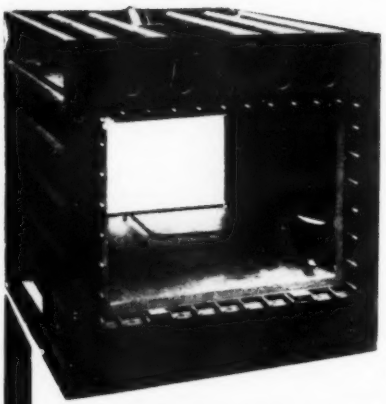

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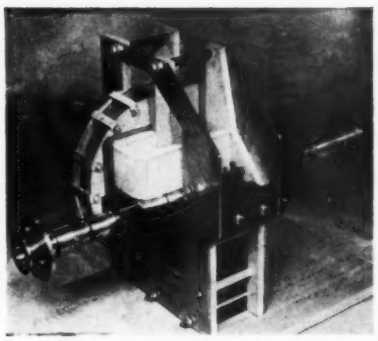

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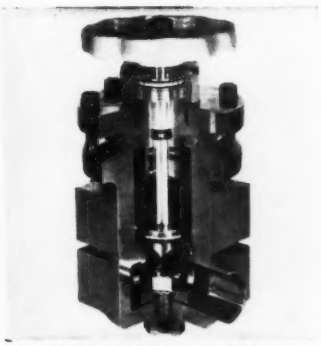

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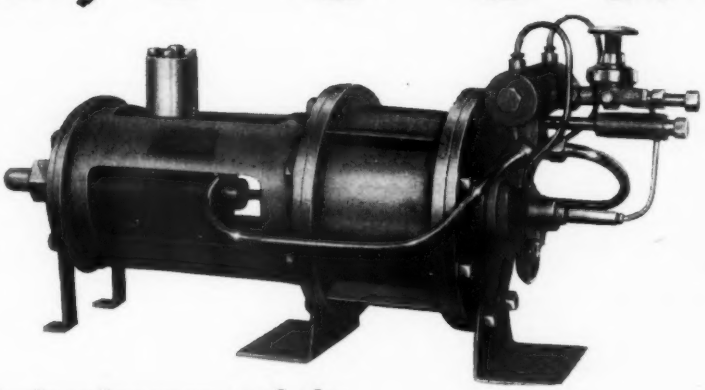

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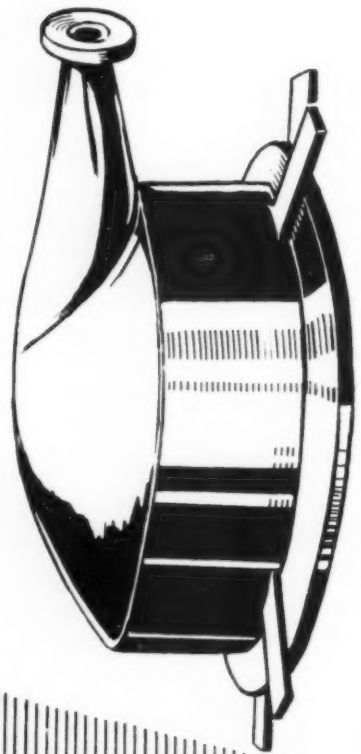

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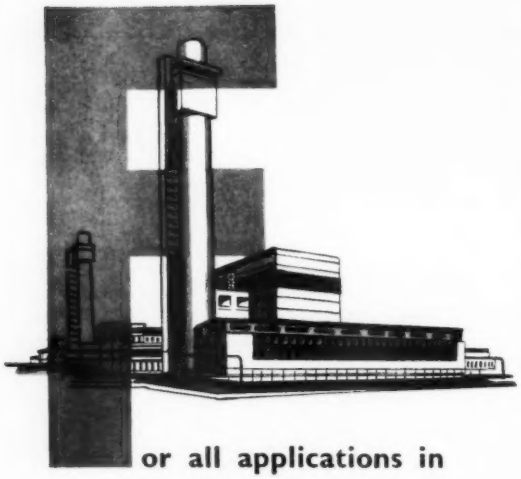

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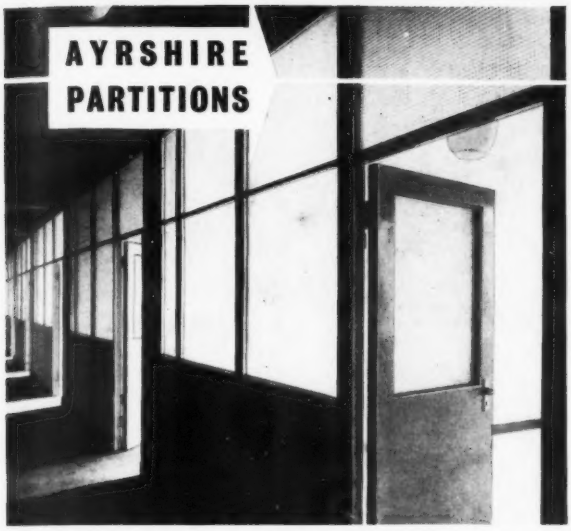

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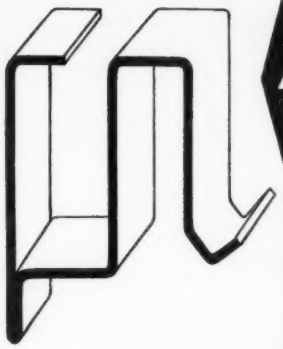

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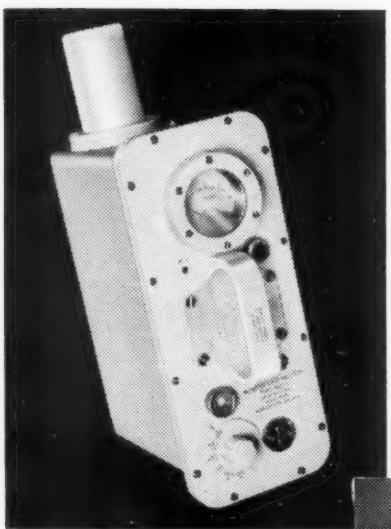

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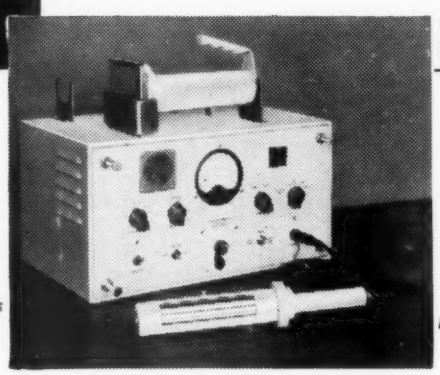

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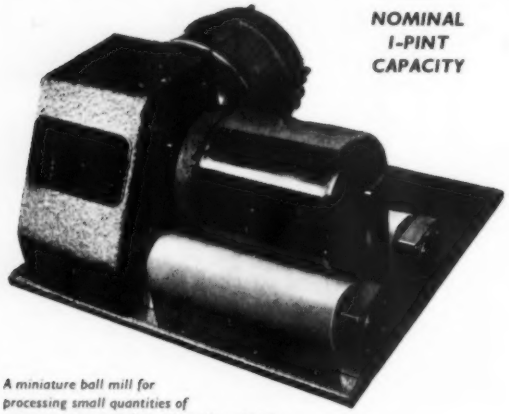

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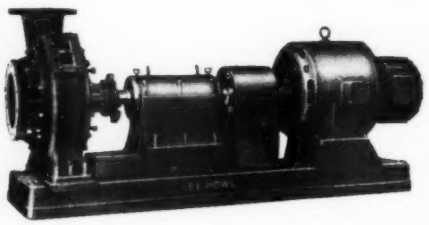

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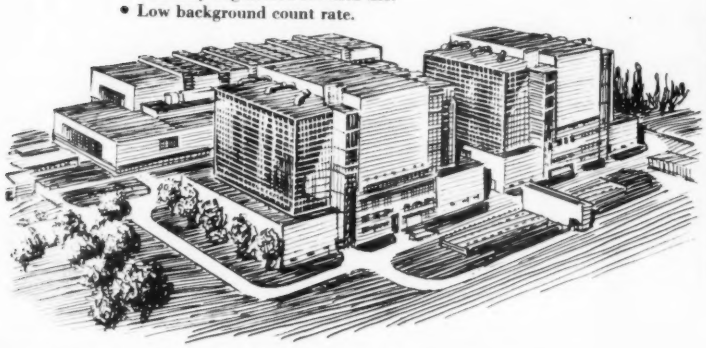

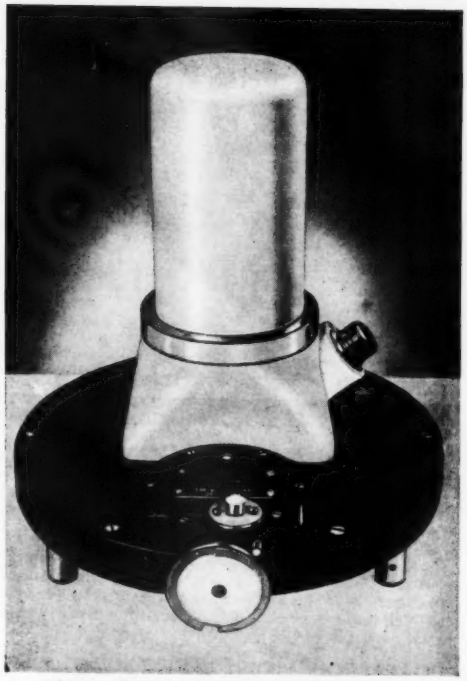

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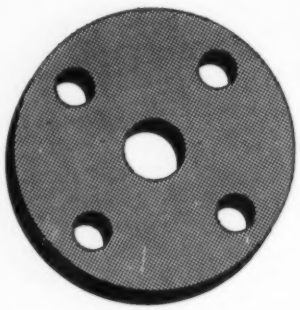

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ATOMIC POWER FOR PEACEFUL USE

For the *fourth time* . . . Mitchell's have been chosen to work on British Atomic Plants

1	*Chapelcross.* Mitchell Construction Co. are the main civil engineering contractors for this important new AEA nuclear power station. The contract, valued at £3½m., includes all buildings and cooling towers.	CHAPELCROSS
2	*Capenhurst.* Mitchell Construction Co. are installing pipework, process plant and equipment at this AEA plant. Six cooling towers are also being built by Mitchells.	CAPENHURST
3	*Springfields.* This contract is for pipework and other plant for the Atomic Energy Authority.	SPRINGFIELDS
4	*Dounreay.* Supply and installation of engineering equipment for the chemical laboratories associated with this new fast-breeder reactor in the north of Scotland.	DOUNREAY

Mitchell Engineering Ltd of London, working as a consortium with their American associates AMF Atomics Inc, and Siemens-Schuckertwerke of Erlangen, are to supply an atomic station to the largest power organisation in the Ruhr, Rheinisch-Westfalisches Elektrizitatswerk AG.

MITCHELL

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